zeroenvy

Streamlining Energy Compliance Modeling in California

Case Studies from BEM Practitioners

Final Report

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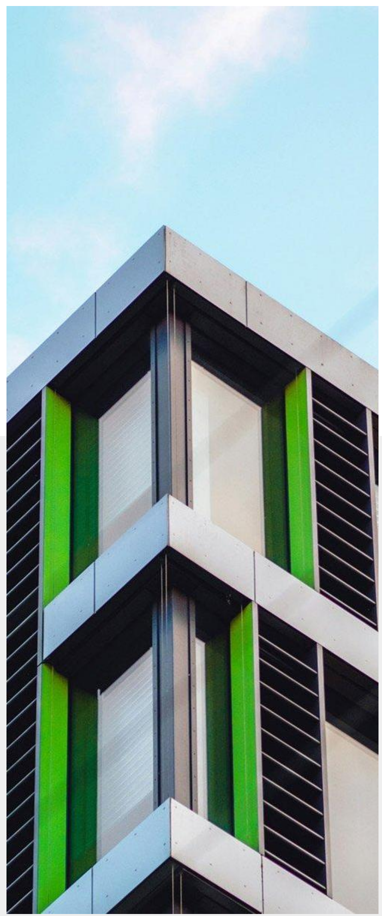

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Executive Summary

This report evaluates key differences between the energy model-based "performance" approaches in the 2019 California Building Energy Efficiency Standards (T24) and ASHRAE Standard 90.1-2019 Performance Rating Method (PRM) by using case study energy models from real design projects.

Approach

- Case study models were developed using IES Virtual Environment software for design consulting work using 90.1 PRM.
- Specific terms were defined to reference the two rulesets and two models for each, including PRM Proposed, T24 Proposed, PRM Baseline, and T24 Baseline. The “T24” models were created by modifying the relevant PRM models for the T24 measure being evaluated.
- Eight ruleset measures were chosen to illustrate challenges known to arise with T24 compliance modeling– added error due to constrained inputs, added complexity or ruleset’s requirements

Key Findings

- The constraints within the T24 software rulesets can result in simulated energy use that deviates significantly from anticipated design and operations.
- Since the T24 compliance model doesn’t represent the design, design consultants are often required to develop two separate models: one for providing useful feedback on developing the building design and a separate one for compliance, which is a time-consuming and often very confusing process for both owners and design teams.
- The PRM approach has proven more flexible and allows the "Proposed" model to align with the actual design and anticipated operation of the future building, including internal gains, setpoints, schedules, and other aspects not directly regulated by software ruleset requirements.
- The PRM approach also provides more flexibility in the modeling software and methods used to represent nonstandard design strategies such as complex HVAC systems synergies with mixed-mode natural ventilation, and custom operating schedules for non-conventional building types.

Conclusion

The findings of this report suggest that T24's current approach to energy code compliance can lead to inaccurate results and complexity for building owners, design teams, and energy modelers that can be avoided. The report recommends that stakeholders involved in developing the California energy code compliance pathway consider the following recommendations:

- adopting a more flexible approach to the current software rulesets which would allow for better alignment between the proposed model and the actual design, and
- to provide a streamlined means of developing a sort of asset rating of the building and systems.

Leveraging widely used standards such as ASHRAE Standard 90.1 PRM or ASHRAE Standard 169 can yield cost savings and other benefits for California. A wholesale shift to the 90.1 PRM approach is not a recommendation of this report.

Introduction

The idea for this project came from discussions during a meeting of the IBPSA-USA California BEM Practitioner Advocacy Committee. Several professionals who provide building energy modeling (BEM) consulting services for high-performance building design organized the committee with the goal of providing better representation of their interests in California energy codes and standards development. A primary theme from the committee's discussions was the effort to streamline California energy code compliance (Title 24, Part 6 or "T24") within a typical high-performance design process that already used energy modeling. Members felt strongly that ASHRAE Standard 90.1's Performance Rating Method (PRM) has historically provided benefits over California's energy model-based compliance pathway. The most significant of these was that the PRM rules were flexible enough to allow the "proposed" model to align with the actual design and anticipated operation of the future building. This includes the specification of internal gains, setpoints, schedules and other aspects of building operation that are not directly regulated by mandatory and prescribe energy code requirements. It also allows flexibility in the modeling software and methods used to represent nonstandard design strategies such as complex HVAC systems synergies with mixed-mode natural ventilation, and custom operating schedules for non-conventional building types.

In contrast to PRM, California's performance approach constrains its "proposed" model definition to the point where the simulated energy use can deviate significantly from anticipated design and operations. Beyond this potential for erroneous results, it often means that two separate models are required: one for providing useful feedback on developing designs, and one for compliance. This is time-consuming and confusing for owners and design teams, and often diminishes the level of performance-focused analysis and design due to budgetary constraints.

This report provides side-by-side comparisons of eight measures in the two referenced standards using case study energy models from real design projects. By evaluating each measure separately the project team was able to better understand the complex influences of the measure on the model and results. Using real design energy models introduced the true complexities and variability from the prototypical models and input assumptions. These complexities are often overlooked when developing code language and modeling rules which is the cause of some of the challenges described in this report.

From a practitioner's perspective, one point of clarification is that there is a preference of ***some*** aspects of the PRM approach compared with the T24 modeling pathway. This does not mean that a complete shift to PRM is recommended by this report. For example, the utilization of the performance cost index (PCI) metric and building performance factors (BPFs) introduced at a 90.1-2013 addendum has not been well received by the practitioner community. This report focuses in illustrating the constraints of the T24 approach and their impact on the design and compliance aspects as mentioned directly within the described measures.

Another relevant note is related to the recent California project nicknamed, "CalPRM". While this project team knows little about the specifics and goals of the CalPRM project, it is known that the project involved developing a research version of the California compliance software, CBECC, that utilized a modified version of a recent PRM version to explore the suitability of the PRM rulesets in California. These included the addition of constraints to the development of the Proposed model described above and evaluated in this report.

The development of the California energy code compliance pathway has consistently leaned toward the use of more "locked down" software compared to approaches of similar code stringency and complexity used in other States and jurisdictions. This report aims to highlight the types of issues and errors introduced by the constraints and complexities inherent in such an approach. It also seeks to encourage a more balanced consideration of accuracy, complexity, and effectiveness in the design and implementation of these compliance rules.

Approach

This project used existing energy models developed for real design projects as case studies to evaluate a number of different ruleset measures between the energy model-based "performance" approaches in the 2019 California Building Energy Efficiency Standards (T24) and the ASHRAE Standard 90.1-2019 Performance Rating Method (PRM). This work focuses on the 2022 nonresidential version of the T24 performance approach and related software, described in the Nonresidential ACM Reference Manual (NRACM or ACM).

The case study models were developed using IES Virtual Environment software for design consulting work. Most projects used the PRM approach in pursuit of LEED certification.

For the energy model analysis described in this report, the terminology related to the two rulesets and two models for each is as follows:

- **PRM Proposed (or Design)**: The primary model which represents the design and which was the "Proposed" model used for 90.1 PRM compliance.
- **T24 Proposed**: A copy of the PRM Proposed model, modified to apply the T24 ruleset measure as described in each evaluation section.
- **PRM Baseline**: A model following the 90.1 PRM rules for the baseline model generated based on the PRM Proposed model.
- **T24 Baseline**: A copy of PRM Baseline model, modified to apply the T24 ruleset measure as described in each evaluation section.

Refer to Figure 1 below for a diagrammatic illustration of the approach to model generation. Note that the "T24" labeled models do not follow all rules of T24 compliance models, but a version of the PRM models with the T24 version of the relevant measure applied.

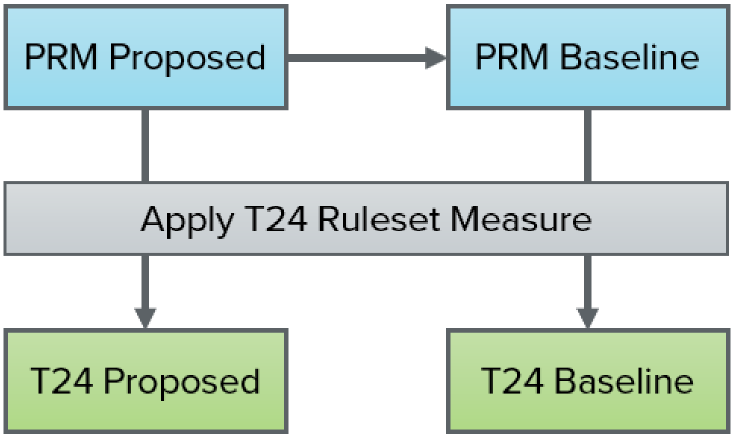


Figure 1. Diagram showing the approach to generating the four models used in measure analysis

Ruleset Measures

This report includes the evaluation of eight (8) Selected Measures, which are part of a larger list that was developed as the first task of this project. The remaining measures are included in Appendix B. Non-Selected Measures, and they may be worth evaluating in a similar manner as part of future work.

Selected Measures

Hyperlinks to code/standard references in the table are to UpCodes (for PRM), and EnergyCodeAce (for T24 NRACM).

#	Measure Name	Design Model Inputs	90.1 PRM Rule	T24 NRACM Rule
1	Equipment Power Density	Modeled per coordination with the project design team, especially for rooms with larger specialty equipment like data or industrial equipment rooms.	Per Table G3.1.12, "EPD shall be estimated based on the building area type or space type category and shall be assumed to be identical in the proposed design and baseline building design"	Per ACM section 5.4.6, EPDs are prescribed to the values listed in Appendix 5.4A based on the selected (lighting) space function.
2	Heating / Cooling Setpoints	Occupied & unoccupied heating & cooling setpoints (where applicable) are modeled per coordination with the design team, especially the mechanical engineer. Schedules are assigned to setpoints, typically based on the intended HVAC system operating hours.	Per Table G3.1.4, "schedules capable of modeling hourly variations in setpoints shall be used. The schedules shall be typical of the proposed building type as determined by the designer and approved by the rating authority".	Per ACM section 5.6.1, "setpoint schedule group is specified for the given space type in Appendix 5.4A, and the schedule values are specified in Appendix 5.4B."

#	Measure Name	Design Model Inputs	90.1 PRM Rule	T24 NRACM Rule
3	Schedules	All schedules are modeled based on coordination with the design team and consideration of building occupied hours, HVAC system operations and the needs of individual spaces, as appropriate. It is common practice to start with default schedules from 90.1 User Manual, T24 Appendices, etc. and adjust if necessary as the design progresses.	Per Table G3.1.4, "schedules capable of modeling hourly variations in occupancy, lighting power, miscellaneous equipment power and HVAC system operations shall be used. The schedules shall be typical of the proposed building type as determined by the designer and approved by the rating authority".	Per ACM section 2.3.3, " The schedule group in the standard design is defined for each building story according to the predominant space function type and the schedule group assignment in Appendix 5.4A. For systems that serve more than one thermal zone, the HVAC schedule group and availability schedule are determined by the most predominant schedule group (by floor area) represented in the thermal zones served". (Definition is incomplete; see evaluation for details.)
4	Window to Wall Ratio (Baseline)	Proposed windows modeled per architectural design. Each window and curtain wall are modeled explicitly. Baseline model is not applicable.	Per Table G3.1.5, baseline total WWR prescribed by building type in Table G3.1.1-1. If building type not listed, fenestration matches proposed up to 40% WWR. Windows applied in proportion by orientation to proposed. WWR based on gross above-grade walls that separate conditioned spaces and semiheated spaces from the exterior air (i.e. above ground).	Per ACM section 5.5.7, baseline WWR matches proposed design up to a max of 40% total and 40% west-facing. Zero fenestration in computer rooms. Exception for ground-floor “display perimeter”. WWR based on gross above-grade walls that separate conditioned spaces from the exterior air (i.e. above ground).
5	Lighting in Unconditione d Spaces	All indoor lighting energy is accounted for towards energy savings calculation in practical uses.	No differentiation between indoor lighting in conditioned vs unconditioned spaces. Therefore, it is considered “regulated” and included in compliance calculation.	Per ACM section 5.4.4, lighting in unconditioned spaces can be modeled and reported, but it is **excluded** in the compliance calculations.

#	Measure Name	Design Model Inputs	90.1 PRM Rule	T24 NRACM Rule
6	Natural Ventilation	Depending on the energy modeling software used, natural & mixed-mode ventilation can be modeled in detail.(bulk airflow and/or computational fluid dynamics).	Per Table G3.1.4 Exception 2, automatic natural ventilation controls for Proposed may vary from the Baseline model to account for savings.	Per ACM section 3.2.3, Natural ventilation is allowed for hotel/motel guest rooms only. The modeling methodology is unknown (i.e. not defined in NRACM and unclear in software).
7	Performance Curves: Chiller	The modeled chiller performance is based on equipment selection and performance curves/ coefficients published by the chiller manufacturer. Performance curves in common practice align with those used within compliance software such as either DOE2 or EnergyPlus.	Not specifically addressed within the standard.	Per ACM section 5.8.2, "Curves are prescribed in Appendix 5.7 given the chiller capacity and type. A separate set of curves are provided for Path A chillers and Path B chillers. The path is determined by comparing software inputs of full-load efficiency and integrated part-load value with the requirements of standards Table 110.2-D."
8	Climate zones	N/A. Climate zone is not relevant to the design except as referenced by applied code or standard.	Per 90.1 section 5.1.4. Climate zone is determined based on the project's location or county in the US. Climate zones published by DOE & ASHRAE with updates over time. 7 ASHRAE climate zones serve California.	Per ACM section 5.2.5. Climate zone is determined based on proximity to the closest City in published data out of 16 California climate zones.

Note: A free UpCodes account may be required to access some of the hyperlinks directly. Otherwise, the user may reference the section in their own copy of the standard.

Non-Selected Measures

The measures below were deemed a lower priority for this project due to time constraints and were omitted. These measures are also included in ***Appendix B. Non-Selected Measures*** for reference, and may be worth studying in future projects or considering in any related future work.

Evaluation Summaries

This section presents each measure that was evaluated as part of the project. The measures are described in greater detail, including the potential issues with one or more rules. Then one or more analyses were conducted on case study models from real projects to highlight and quantify these issues, as appropriate.

Measure 1: Equipment Power Density

Equipment power density (EPD) represents the electricity use of unregulated equipment that gets plugged into electrical outlets in a building. It is usually specified as a watt-per-unit-area (e.g. W/ft^2) and varies in design models based on the anticipated use of the building and spaces within.

In both Title 24 and 90.1 PRM, unregulated equipment is modeled identically in the proposed and baseline models. At first, this may appear to neutralize any impact. However, as the EPDs increase, internal heat gains in the spaces also rise. This increase directly impacts regulated energy end uses, such as heating and cooling systems, which in turn can affect compliance outcomes. PRM directs the modeler to use estimated EPD values based on building area or space types in the project (i.e. same as the “design” model estimates). In contrast, T24 prescribes EPDs based on the space type selected from a predefined list.

The T24 approach is restrictive for the following reasons:

- Impact on energy use. Prescribed EPDs in T24 may not deviate from actual/design values, influencing the heat gains which directly impact the *regulated* energy consumption in these spaces.
- Impact on HVAC operation. EPD variations from the design also change the operating capacity of HVAC systems in the compliance model. Increased operating capacities may exceed the design capacity, leading to unmet load hours. Increased or decreased operating capacities will change the modeled part-load ratio (percentage of operating vs available capacity) which also impacts energy use.

The case study analysis described below provides more detail about these impacts.

Case Study: Office And Operations Center, High EPD

The ***Office and Operations Center*** case study model is a new office building in San Francisco, California that extends an existing, large transit hub. It will provide new office space for executive staff and an integrated operations center. The operations center has several spaces that provide office-like functions for staff using significantly more computers, large displays and other equipment leading to unusually high EPD values compared with the prototypical office building upon which T24’s EPD values are based. The table below summarizes the area-weighted average EPD values between the design/PRM model and T24 by space type and building-wide.

Space Type	Design/PRM EPD (W/ft^2)	T24-2022 EPD (W/ft^2)
Offices & conference rooms	1.8	1.4
Electrical rooms	17.0	3.0
Server rooms	18.4	20.0
Support spaces	0.7	0.3
Area weighted avg.	**2.5**	**2.0**

Analysis & Results

Comparing the Design / PRM Proposed model with the alternate version using T24 EPDs ("T24 Proposed") shows differences in energy use of the "receptacle equipment" end-use category, as well as HVAC-related end-uses.

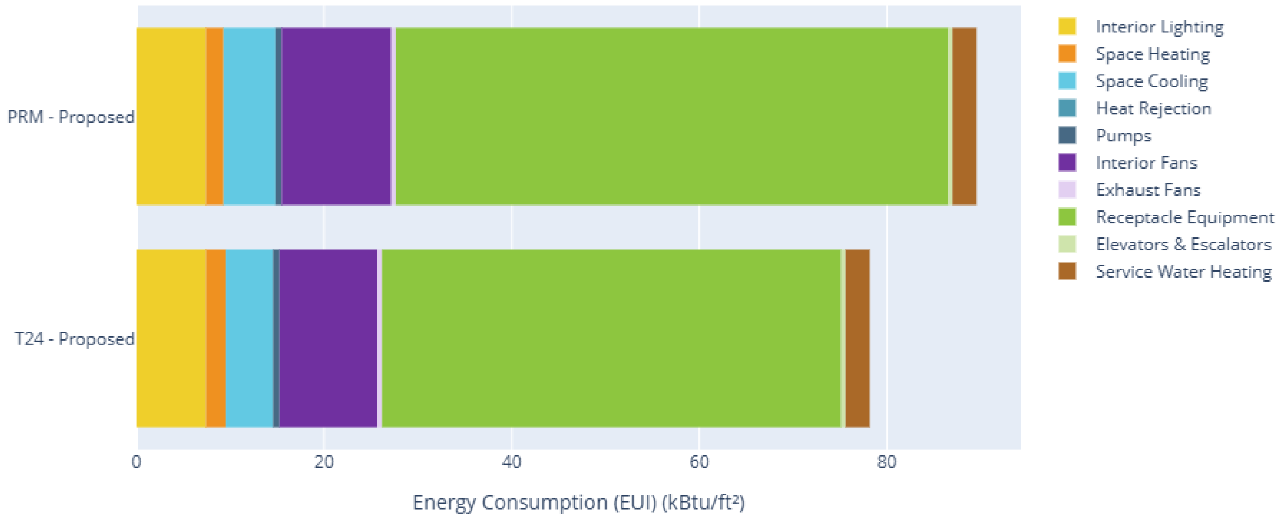


Figure 2. Energy end use comparison between the PRM and T24 Proposed models.

The results in Figure 2. illustrate the following differences based on a difference in EPD of 20%:

- 17% reduction in Receptacle Equipment (unregulated end-use category)
- 8% reduction in space cooling
- 11% reduction in interior (HVAC) fans
- 12% increase in space heating

The aggregate impact on regulated end-use categories affected by this change in unregulated loads is about 1.7% of the whole-building consumption. This is relatively small, but these savings are diluted by the high receptacle equipment energy use of this project and others could have a greater impact (especially if a project anticipates lower-than-T24-prescribed EPDs).

In a compliance scenario, the most important impact is the resulting margin between the proposed and baseline models. We can use the case study results to understand how this change in EPD can impact the Proposed and Baseline models differently, leading to differences in compliance margin. The figure below shows the savings of 16% in the original PRM models being reduced to 10% when using the T24-prescribed EPD values.

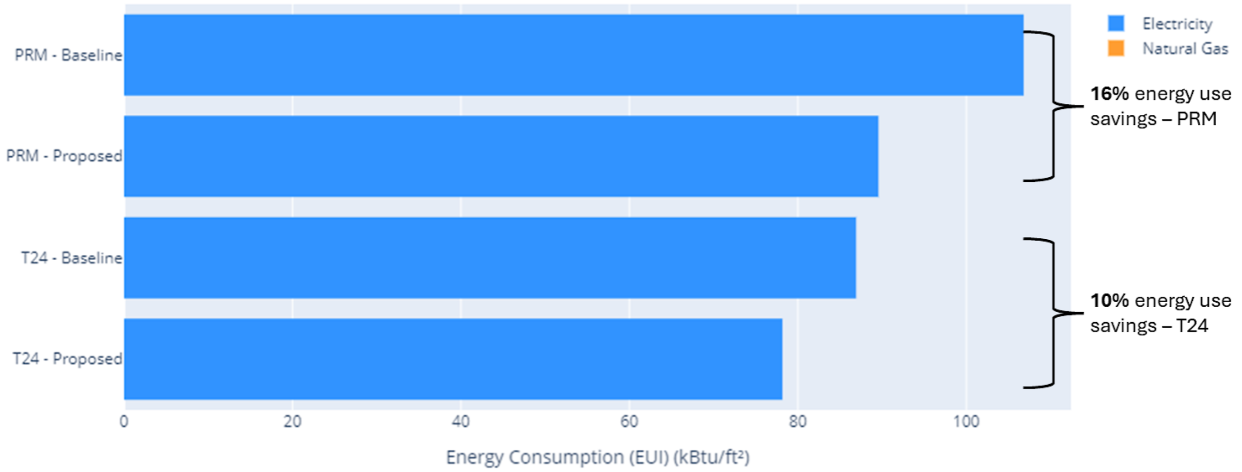


Figure 3. Energy consumption differences between the PRM and T24 proposed and baseline models.

One might assume that adjusting EPD values equally in both proposed and baseline models would have an equal impact. However, that is not true with the case study. The change in EPD heat gain may be equal, but this is only one component of the heating/cooling load in each space. Furthermore, the varying configurations of HVAC systems between the models, impacts on part-load and other issues can have dramatic effects on the operating efficiency of the systems.

The most significant factor impacting the difference in energy between the two sets of models (16% down to 10%) is HVAC fan energy. The main HVAC system in all models uses central variable-air-volume (VAV) fans where part-load ratio has a significant impact on energy consumption due to fan affinity laws and supply air temperature resets when deployed. The table below shows just the fan energy end-use for the four models. In the "PRM" column, the Proposed model utilizes the fan power and sizing from the design, and the Baseline model utilizes a similar VAV reheat system. The T24 Proposed model uses the same HVAC sizing but with the lower T24 EPDs, and the T24 Baseline model is a copy of the PRM Baseline model that is re-autosized with reduced and EPDs.

Fan EUI (kBtu/ft^2/yr)	PRM	T24
Proposed	11.66	10.44
Baseline	17.95	12.24
Savings	**6.29 (35%)**	**1.8 (15%)**

The savings between the two PRM models are 35%. This is severely reduced to 15% for the T24 models. One might expect the models to be affected similarly, or for the Proposed model to show further savings with reduced EPDs due to fan affinity laws and a greater turndown compared to the larger fan capacity in the design. This is not the case, however. The exact reason for this is unclear, but very likely it is due to the zoning of the air handling units in the proposed versus baseline models compounded with the impacts of a supply air temperature reset. The point is that departures from a "design" model due to constraining the gains can have a large and complicated impact.

A second example is considering cooling efficiency. When revising the PRM Proposed model to use T24 EPDs, the annual average cooling efficiency decreased from 3.15 to 3.02 COP. While coil capacities remained the same in these two models, the reduced loads and part-load performance curves of the cooling systems led to operating conditions that were 4% less efficient on an annual basis – another source of error due to the differences in the EPD loads.

CONCLUSION

The anticipated energy use and heat gain of unregulated equipment in buildings can deviate from the values prescribed by T24 based on the selected space type. In the case study project, this deviation was known during the design based on the equipment planned for these spaces. Using prescribed values in lieu of these anticipated values led to changes in heating, cooling and fan energy end-uses and a decrease in the percent savings between proposed and baseline. This error may range from 0% to well over 6%, depending on the project.

This could be addressed by allowing user-entered EPD values in the software, or by auto-sizing proposed & baseline HVAC systems to avoid the issues due to part-load performance and streamline the process. Refer to the main conclusion section for a more detailed discussion of these options.

Additional considerations / further impacts…

Building types such as data centers, laboratories, hospitals, commercial kitchens and manufacturing plants that have *higher* EPDs in the design than T24-prescribed values are currently showing artificial savings.

In the reverse scenario, projects that have *lower* EPDs have undesirable impacts on modeling results and code compliance.

Measure 2: Heating / Cooling Setpoints

Heating and cooling setpoints define the indoor temperature thresholds that trigger the operation of heating and cooling in conditioned spaces or zones. They are an important input setting when sizing HVAC systems, and they are also actively used during energy simulations. While these two situations can use different input values, it is common practice to use a single value for heating and another for cooling. Unoccupied or setback temperature setpoints may also apply, which are usually relaxed from occupied setpoints by a few degrees to save energy when the building is unoccupied. In design practice, setpoints are tailored to the intended use of a space and can vary for similar space types across different projects, depending on operational requirements.

In both T24 and PRM, the temperature setpoints are modeled identically in the proposed and baseline models. The PRM approach directs the modeler to use setpoints “typical of the proposed buildings type”. It is standard practice to select values that align with the design and intended operation. In contrast, T24 prescribes setpoints based on a space type selected from a predefined list.

The T24 approach is restrictive for the following reasons:

- Impact on energy use. Prescribed setpoints in T24 may deviate from expected values, directly influencing heating and cooling-related energy consumption.
- Impact on HVAC operation. Deviations from the setpoints used by the engineer to size HVAC systems will lead to operating part-load ratios that may also influence the efficiency of these systems and min or max limitations.
- Impact on unmet load hours. If a prescribed setpoint is more stringent (e.g. higher heating or lower cooling setpoint), this may lead to unmet load hours, which is a compliance issue.

The case study described below provide more details about these impacts.

CASE STUDY I: LIFE SCIENCES OFFICE/LAB, TIGHT SETPOINTS

This ***Life Sciences Office/Lab*** case study model is a new construction development consisting of three buildings located in the San Francisco Bay Area of California. The project was developed as a “warm shell” with a complete envelope, all central HVAC and water heating systems, and interior fit-out to be completed after tenants lease the space. The targeted tenants are life sciences companies, so the basis of design was assumed to be 50% office and 50% laboratory areas in leasable areas (approximately 70% of gross floor area, excluding parking). The future tenant space types were modeled using generic core/perimeter zoning.

The labs and offices were engineered for tighter temperature control compared to a prototypical office building to ensure experimental accuracy, preserve sensitive materials, and generally support the future work activities in the building. Since labs and offices occupy most of the conditioned floor area, this case study highlights the differences in using a lower cooling setpoint for the design/PRM model versus the prescribed T24 setpoints for these spaces. These input differences are summarized in the table below.

Office & Lab Setpoints	Design/PRM	T24
Cooling	72°F	75°F
Heating	70°F	70°F

Analysis & Results

Decreasing cooling temperature setpoints while leaving heating setpoints the same has a direct impact on energy consumption. Considering the Proposed model in the design/PRM scenario versus the version with T24 setpoints, we see the following primary differences (as shown in ***Figure 4*** below):

- 10% reduction in space cooling
- 5% reduction in space heating
- 5% reduction in interior (HVAC) fans
- 3.4% reduction in total energy use

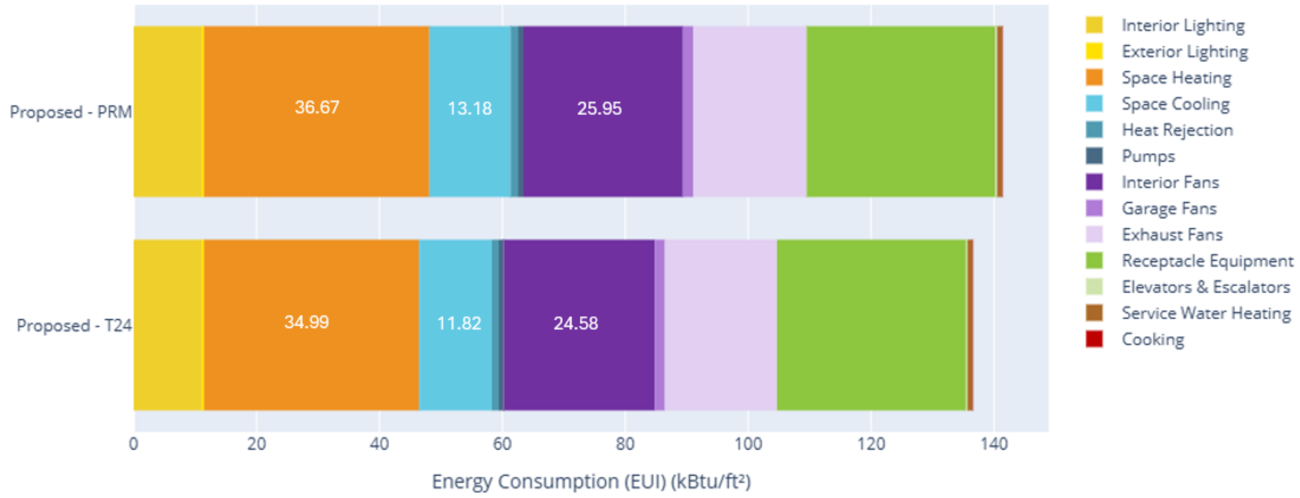


Figure 4: Energy end-use comparison due to different setpoints in proposed models

Cooling and fan energy reductions were expected due to the reduced cooling setpoint and resultant increase in cooling load. One might expect heating to be unaffected since the heating setpoints did not change. However, the HVAC controls in actual buildings and in energy models use control logic that includes throttling ranges and proportional gains (or PID loops) which mean that heating and cooling changes often affect each other.

As we saw with the EPD measure, we again see that the differential between Proposed and Baseline models are affected to different degrees with the setpoint change, even though the changes are the same. ***Figure 5*** below shows that savings of 20% in the original PRM models were reduced to 17% when using T24 prescribed setpoints in both models. This is again because HVAC system operation is complex and making the same change on two different models does not always have an equal impact.

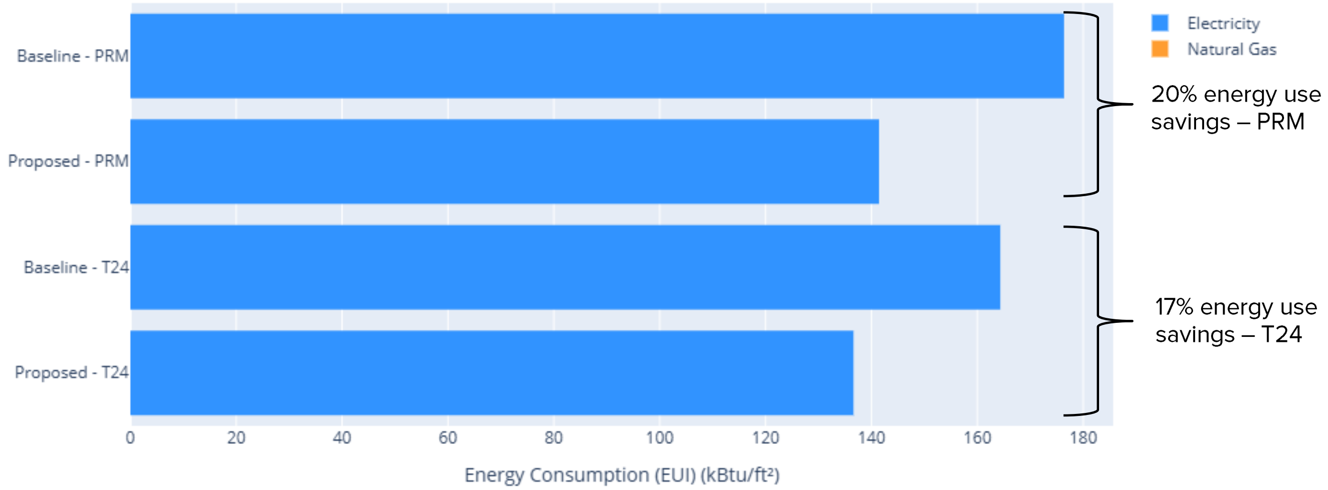


Figure 5: Energy savings difference due to setpoints

CONCLUSION

Heating and cooling setpoints are essential in energy modeling, and they directly affect the HVAC operation and energy consumption. The case study shows that T24's prescribed setpoints can lead to inaccurate HVAC energy use estimates, inaccurate system sizing in the proposed model, and equipment turndown limitations, reducing overall energy savings. These discrepancies, along with differences between baseline and proposed models, result in a reduced compliance margin and different energy savings compared to the 90.1 PRM models.

Additional considerations / further impacts...

Projects such as museums, healthcare and manufacturing facilities, that require tight design temperature control cannot be represented properly in the T24 approach.

CASE STUDY II: COMMERCIAL KITCHEN, RELAXED SETPOINTS

This ***Commercial Kitchen*** case study model represents a commercial kitchen space in a new office building in Los Angeles, California. The original project consisted of several floors in a high-rise office building. For this analysis, the analysis and results pertain only to the kitchen space and HVAC systems that serve it, and all other energy use was excluded.

This kitchen space was designed with setpoints of 85°F in cooling and 65°F in heating to reduce energy used to heat and cool the space. These setpoints represent a common kitchen design practice. In addition to this, thermal comfort in kitchens is influenced by factors like increased airflow, radiant gains from cooking equipment, and specialized hoods which aim to capture heat before it is added to the room. It is difficult to accurately capture all these factors in modern BEM tools, let alone in compliance modeling, which further increases the likelihood of error in modeling energy use associated with these spaces.

The table below summarizes the differences in heating and cooling setpoints between the design/PRM model and the prescribed T24 setpoints for the kitchen space.

Kitchen Setpoints	Design/PRM	T24
Cooling	85˚F	75˚F
Heating	65˚F	70˚F

Analysis & Results

Reducing the cooling temperature setpoint in the kitchen below that which the HVAC system was designed for meant that the lower setpoint could not be maintained. The energy modeling industry uses a term called "unmet load hours" (UMLHs) to quantify this effect, which is calculated by counting the total hours in a simulation when any zone temperature falls a certain amount outside of the heating or cooling setpoint. Figure 6 below shows the UMLHs of the Design/PRM Proposed model vs the T24 Proposed model which replaces these setpoints.

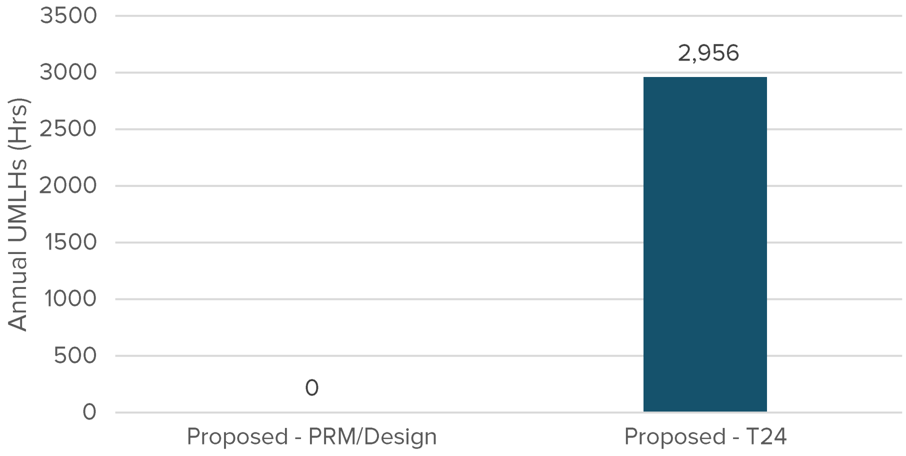


Figure 6: Column chart comparing kitchen UMLHs due to varying setpoints in proposed models

Since the T24 NRACM states that UMLHs cannot exceed 150 hours in any simulation, this result causes the model to fail compliance, even if the energy results passed. Resolving UMLHs for compliance would require revising HVAC system capacities in the Proposed compliance model so that it does not exceed the UMLH limit. Therefore, the next step in the analysis was to make this revision and compare the revised energy results. The cooling and heating capacities of the kitchen's HVAC system are shown in Figure 7 below, indicating an 111% increase in cooling capacity and 15% increase for heating.

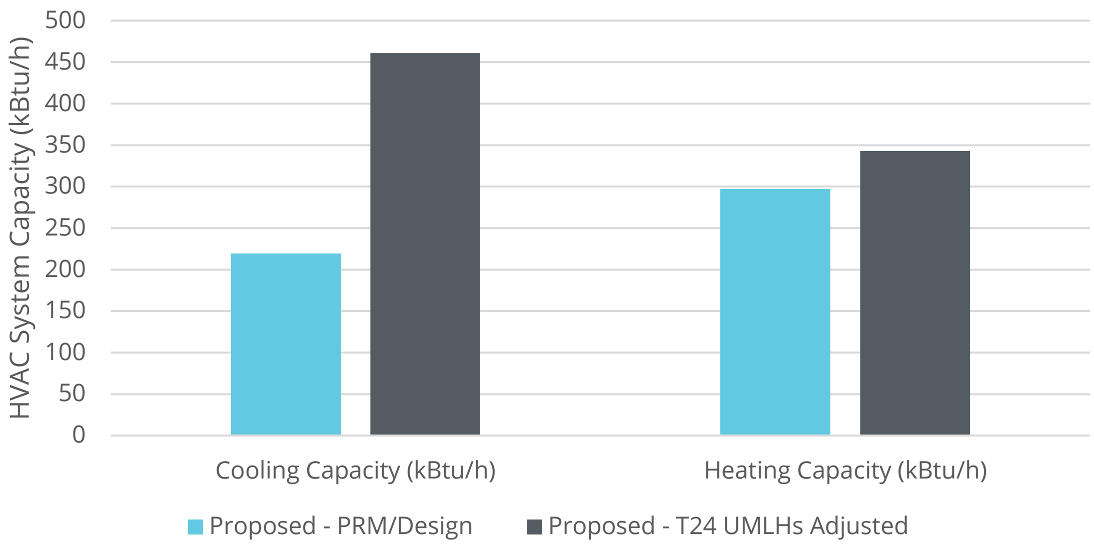


Figure 7: Kitchen HVAC system capacity comparison required to meet T24 setpoints

The revised capacities would resolve UMLHs, theoretically allowing the simulation to comply if that were the only issue. However, the energy use of the larger HVAC system controlling to tighter T24 setpoints increased significantly, as shown in Figure 8 below.

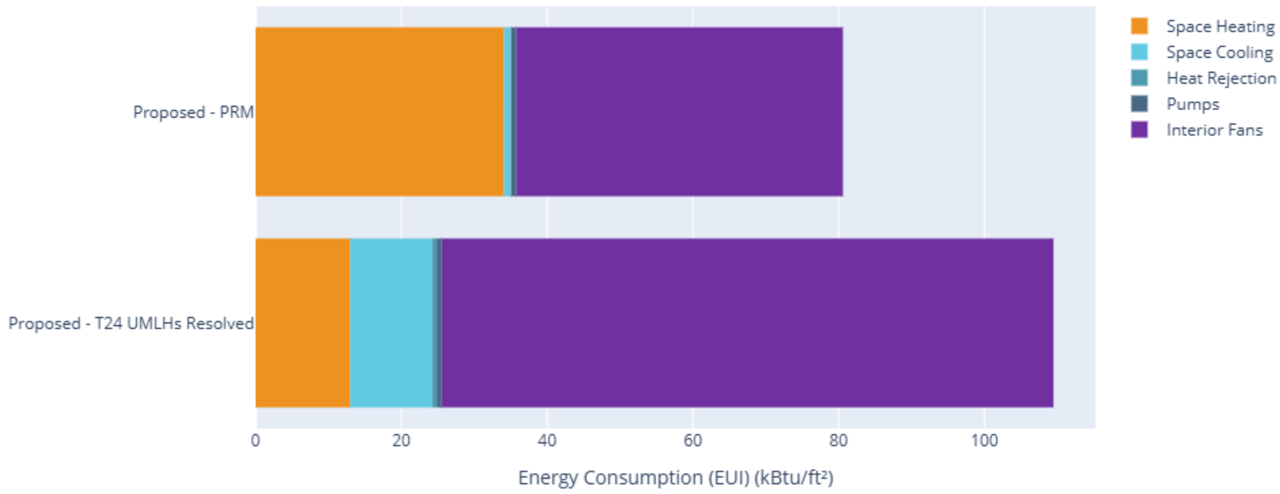


Figure 8: Energy consumption comparison for the kitchen space with adjusted capacities

The results show the following variations for HVAC end uses based on the differences in setpoints and increased capacities:

- 1122% increase in space cooling,
- 63% reduction in space heating, and
- 87% reduction in interior (HVAC) fans.

On an aggregate basis, the T24 proposed model results in 36% increase in HVAC related energy end uses for the kitchen space, compared to the PRM proposed model. While the change in setpoints is applied consistently between the Baseline and Proposed models, the increased energy use for the systems would increase the importance of their energy savings or detriment compared to the energy used by other end-uses and systems in a model, which could certainly impact compliance.

CONCLUSION

This case study highlights the challenges posed by T24's prescribed setpoints in accurately representing design conditions for certain space types like a commercial kitchen. By prescribing tighter setpoints in the T24 Proposed model, this can lead to UMLHs and failure to comply. This triggers the need for manual revisions to the modeled systems to deviate from the design, and cause considerably more energy use by the systems.

These complications can be avoided by allowing user-input temperature setpoints for these spaces, or by auto-sizing all HVAC systems in the compliance software.

Additional considerations / further impacts...

Similar scenarios with more relaxed setpoints than the T24 prescribed setpoints could apply to mechanical, electrical, and data rooms, warehouse or storage spaces, manufacturing areas, or spaces that utilize radiant heating/cooling systems with ceiling fans that provide adequate thermal comfort at higher dry-bulb temperature setpoints.

Measure 3: Schedules

Building schedules define the patterns of use or operation for internal loads like occupancy, lighting, equipment, heating/cooling setpoints, HVAC availability, infiltration, and other functions. A collection consisting of each of these schedules for a particular use case (e.g. office, assembly, etc.) is referred to as a "schedule group".

In energy modeling, schedules are typically published on an hourly basis for the simulation year, although modern BEM software supports more detailed schedules for sub-hourly simulation time-steps. For design-focused energy modeling, it is common practice to use generic schedules from 90.1 User Manual or T24 NRACM Appendix 5.4 as a starting point, and then adjust those so that space schedules align with HVAC system operation and building occupied hours. Some energy modeling practitioners / consultants will apply building-wide schedules to all space types within a building, ensuring consistency but not accounting for the diversity of different occupancy across a building. Others will use templates where each space type has a predefined schedule group applied (office, assembly, etc.), capturing diversity but requiring extra work to align with building occupied hours.

PRM allows user-defined schedules and supports either of the aforementioned approaches. T24 publishes data following the second approach described above (schedule groups by space type) but the compliance model determines the dominant schedule group per floor and applies that schedule group for all spaces. This T24 approach may be further modified in HVAC systems serving multiple floors, which the case study analysis explores in greater detail.

The T24 approach to the operating schedules is problematic for the following reasons:

- Prescribed schedules in T24 may vary from actual building operations, directly influencing energy use across most end-use categories.
- Applying the same schedules for all spaces on a floor (or in a building) does not account for the diversity of internal gains, therefore, it affects the HVAC system's operating efficiencies, as well as the heating and cooling energy
- Determination of HVAC system operating hours based on the number of floors served by the system may lead to different HVAC schedules in the Proposed versus Baseline models which

deviates from the intent of both modeling standards. This approach causes further misalignment with other schedules such as infiltration.

The case study analysis described below provides more detail about these impacts.

CASE STUDY: SIMPLE OFFICE BUILDING, SCHEDULES

This ***Simple Office Building*** case study model was developed for this project to illustrate the T24 modeling rules related to schedules being impacted by HVAC zoning. Real projects were available, but explaining the complex rules was challenging so the team opted for a simpler model for this measure. The model is a 3-story office building, primarily consisting of offices and conference rooms, along with common spaces like a cafeteria. The building's programming assumes Level 1 is primarily conference rooms, while Levels 2 and 3 are offices. The PRM Proposed model utilizes a packaged VAV reheat system with five AHUs zoned vertically (i.e. each serving three vertically stacked spaces). The PRM Baseline model utilizes the same system type but with three AHUs, each serving a floor, following the PRM system map (which is also used in the T24 NRACM system map).

The case study evaluation describes differences between design/PRM modeling approaches and T24 NRACM rules for three types of schedules, each having unique issues: internal gains, HVAC system operation, and infiltration.

Figure 9 below summarizes the types of schedules in the original case study model (Design/PRM Proposed), followed by the T24 overrides for spaces, and then the HVAC system schedules. The colored boxes are labeled with the space type, and colors align with the schedule group per the legend. The "T24: Spaces" level shows the schedule group overrides based on the dominant group for each floor. Since the Proposed model has AHUs serving all three of these levels and two schedule groups, the "T24: HVAC" graphic indicates that these AHUs are forced to operate 24/7.

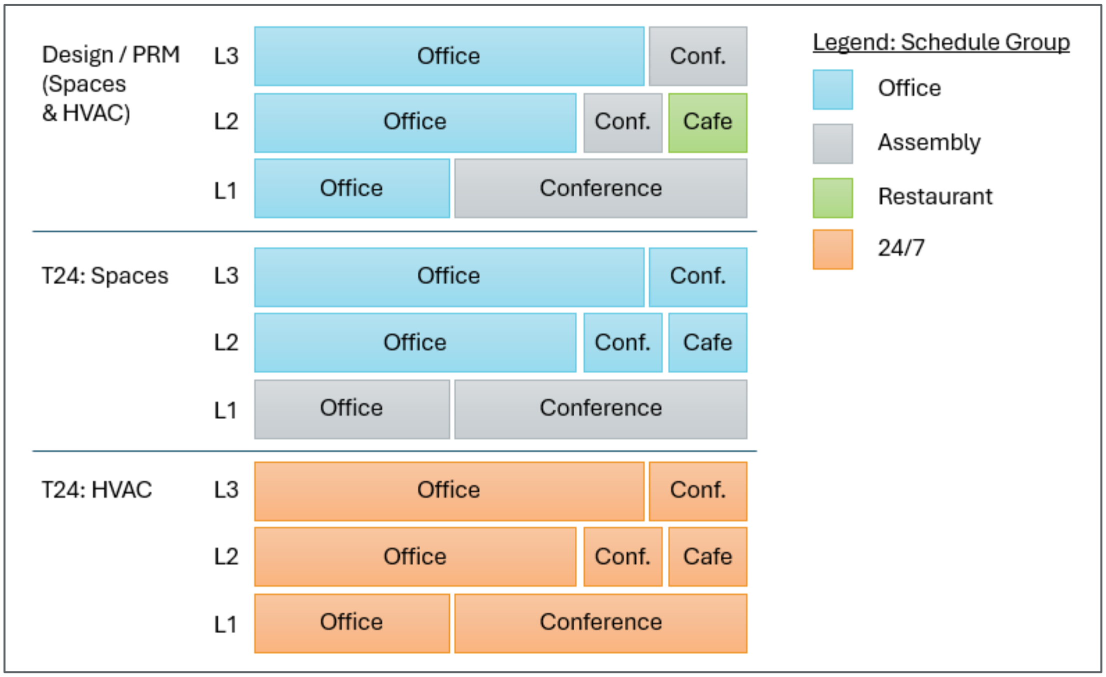


Figure 9. Schedule group rule differences

Note: Please refer to the figures below for additional visualization on the differences between schedules for internal gains, HVAC system operations and infiltration.

Analysis & Results

Internal Gains

Internal gains typically refer to occupancy, lighting and equipment (or receptacle) energy model inputs. Figure 10 below shows the difference in the energy use for a selected space and day in the case study model between the original design/PRM Proposed schedule and prescribed T24 office schedule. They both increase near building occupied times around 06:00 and return to the low nighttime load around 23:00. The design schedule reaches a higher peak and starts to drop much earlier in the evening (around 17:00 versus 22:00). The total difference in the average gain (or equivalent full-load hours, EFLHs) would have the most direct impact on energy use in the relevant end-use category.

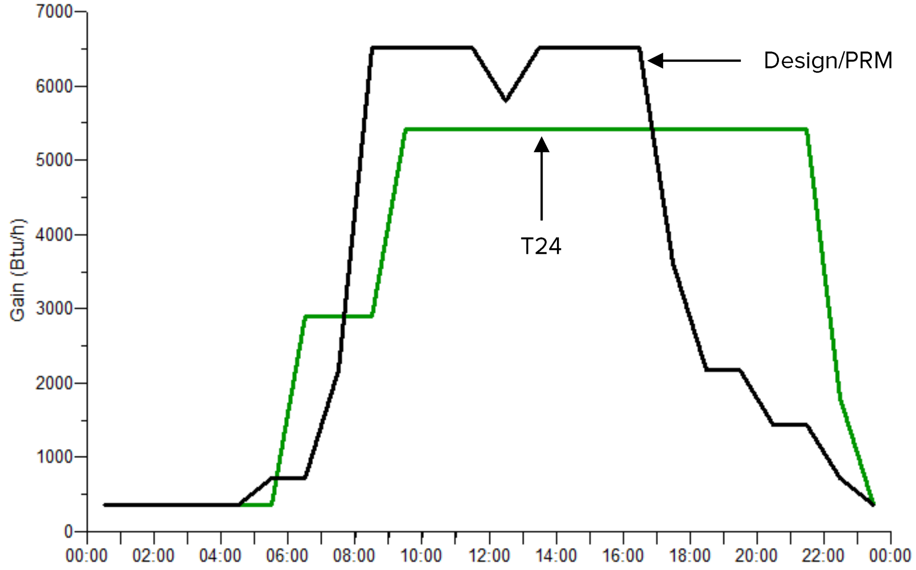


Figure 10: Differences in the receptacle schedules in proposed models

HVAC System Operation

As discussed above and shown in Figure 9, the HVAC operation of the T24 Proposed version of the model is forced to operate 24/7 due to the NRACM rules. Figure 11 below shows this difference for a selected day compared to the Design/PRM Proposed model, where the y-axis indicates "OFF" as 0 and "ON" as 1.

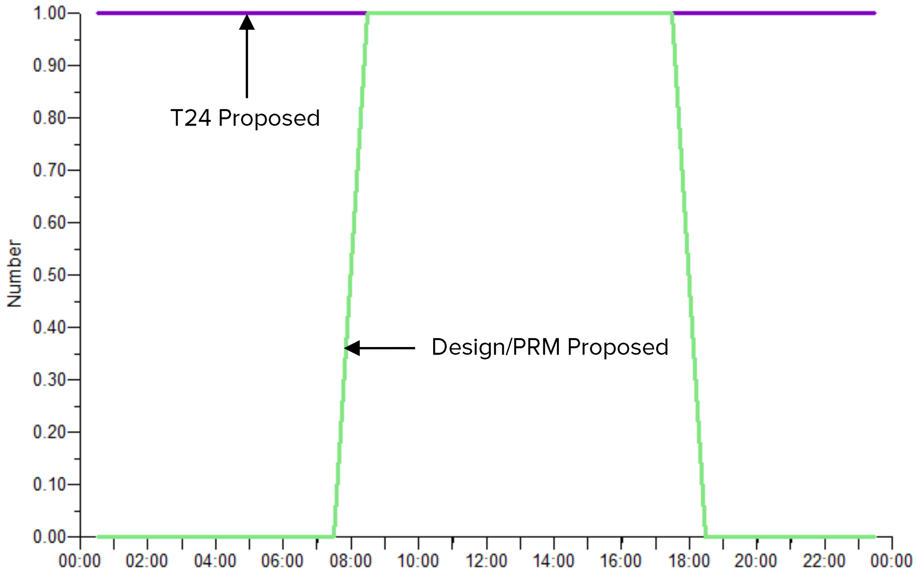


Figure 11: Differences in the HVAC schedules in proposed models

As compliance margin is often the most important result in a compliance scenario, the next figure shows a similar comparison between the T24 Proposed and T24 Baseline versions of the model.

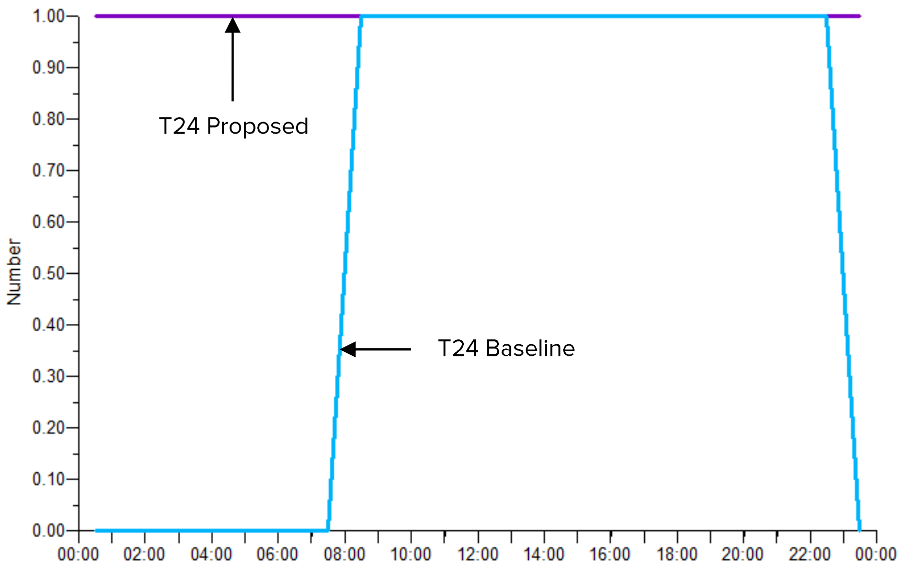


Figure 12: Differences in the HVAC schedules in T24 proposed and baseline models

Infiltration

It is common practice in nonresidential energy modeling applications to enable infiltration only when the HVAC system is scheduled off. This follows the assumption that the buildings are positively pressurized by introducing ventilation air during occupancy. The T24 NRACM and published schedules typically follow that same assumption. However, this case study analysis shows that this assumption does not carry through if an HVAC system is overridden to operate 24/7. Figure 13 demonstrate this showing the resulting infiltration and HVAC operation for a typical day.

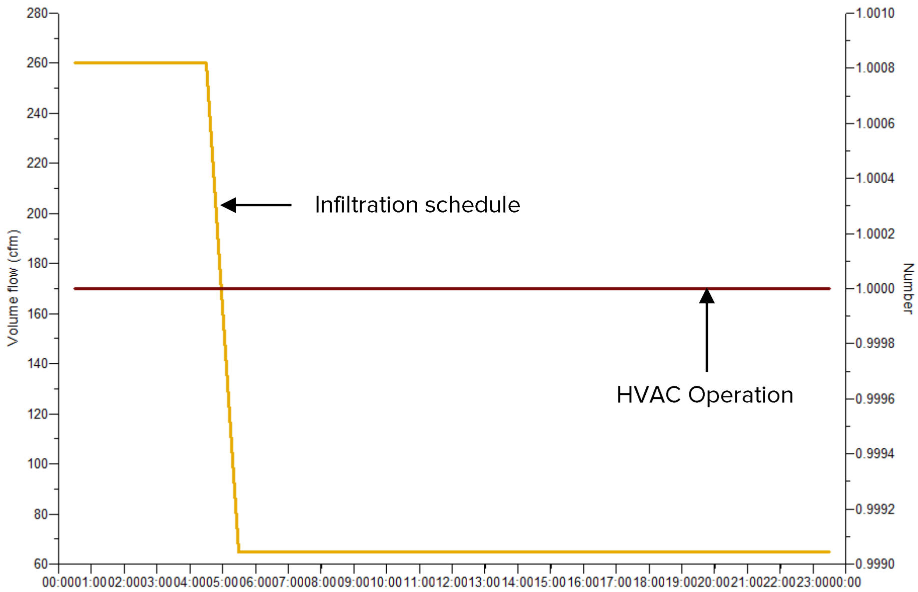


Figure 13: Differences in the Infiltration and HVAC schedules in T24 proposed model

Overall Energy Results

Comparing the Design / PRM Proposed model with the alternate version using T24 schedules ("T24 Proposed") reveals differences in energy use across all end-use categories, with the greatest impact on HVAC-related end uses.

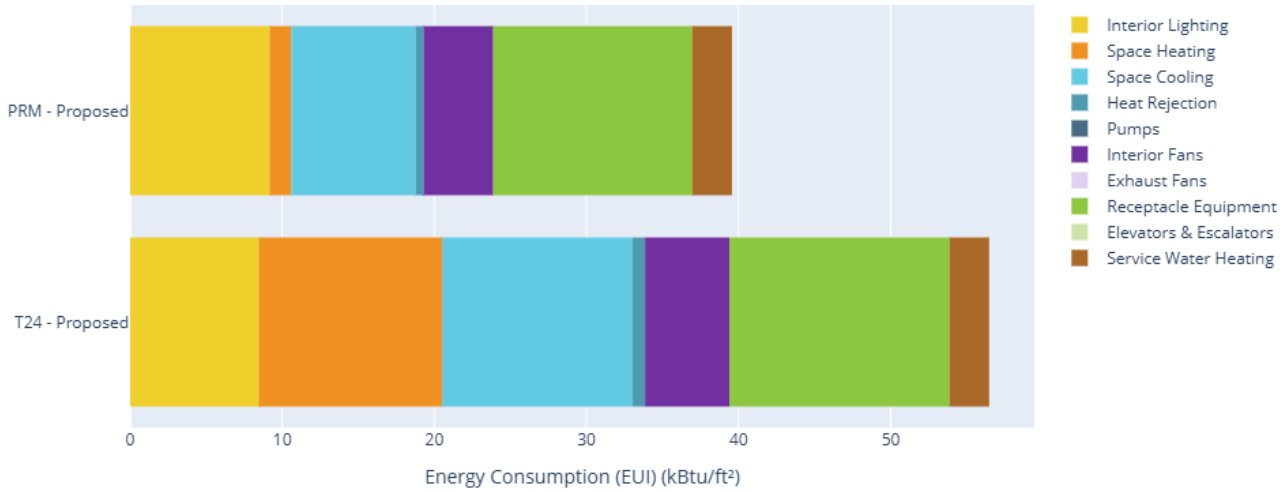


Figure 14: Energy end-use comparison for T24 and PRM proposed models

The differences in the T24 Proposed model stem from variations in schedules for internal loads, HVAC system operation, and infiltration, resulting in:

- 750% increase in space heating,
- 53% increase in space cooling,

- 21% reduction in interior (HVAC) fans,
- 11% increase in receptacle equipment, and
- 8% reduction in interior lighting.

Overall, these changes lead to a 43% increase in whole-building energy consumption for the T24 Proposed model and a 12% increase for the T24 Baseline model compared to their 90.1 PRM counterparts. These discrepancies significantly impact compliance results.

The case study results demonstrate how differences in schedules disproportionately affect the proposed and baseline models, reducing the original 20% savings in PRM models to -2% in T24 models due to overridden schedules.

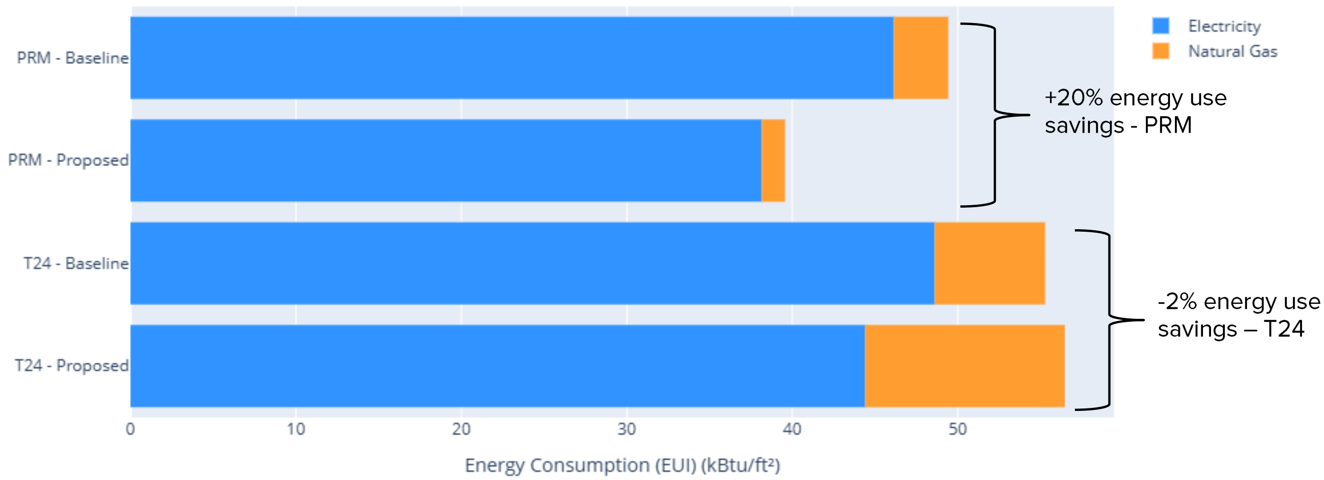


Figure 15: Energy savings difference due to schedules

Overriding schedules in T24 based on predominant space types may seem like it would result in consistent schedules between baseline and proposed models, resulting in compliance margin similar to 90.1 PRM. However, the results of this analysis prove significant variations due to the compounding of the various NRACM schedule group rules.

CONCLUSION

The most significant observation related to schedules occurs when an HVAC in the Proposed model serves multiple floors with a different space type makeup. This can lead to the HVAC system operating 24/7 in a T24 Proposed compliance model whereas the T24 Baseline system will turn off HVAC systems during unoccupied hours. The revision of this specific rule should be treated as a top priority to prevent erroneous compliance penalties. A short-term solution for consideration would be to set the system to operate if any of the space or zone HVAC availability schedule requires conditioning.

Even if the HVAC operation schedule issue is resolved, there are still issues caused by overriding all of the schedules in a compliance model. They can vary significantly from the expected occupancy of the building, leading to differences in energy use and their impact on other end-use categories.

Another observation is that the profile of typical occupancy schedules does not include the types of fluctuations common in spaces in a building. For example, a space that is served by an HVAC system that has local demand-controlled ventilation (DCV) or occupancy sensor ventilation controls (OSVC) will not allow these controls to function properly if the occupancy never drops to zero during the day.

To summarize, the following recommendations related to schedules in the T24 NRACM should be further evaluated:

- Consider revising the rules that force a 24/7 operation on HVAC systems that serve multiple floors regardless of the space type makeup.
- Consider allowing user-input schedules that allow a user to align with the design and intend operations.
- Consider redeveloping the schedule rules altogether to avoid overriding schedule groups by floor or system. For example, space-by-space schedules can be per selecting space type, and HVAC operating schedules can operate as-needed based on those. This may also involve revising schedules throughout the model based on building type so that all schedules and HVAC system operation for an office building, for example, align with the occupancy hours of typical office buildings.

Additional considerations / further impacts…

The case study model uses a simplified office building model. However, the concerns raised in this section could affect any building project for which the prescribed schedules do not represent the intended operations.

Measure 4: Window to Wall Ratio (Baseline)

Window-to-wall ratio (WWR) represents the proportion of a building's above-grade exterior walls that are covered by windows, expressed as a percentage. This is a derived value based on the window and exterior walls specified in the model. Energy model geometries are typically modeled in 3-dimensions in modern design practice, although many compliance models also use 2-dimensional methods.

Windows provide building occupants with views to the outdoors and allow natural daylight into spaces. However, they bring solar heat gain and are typically inferior in terms of thermal insulation compared with insulated exterior walls and, therefore, increased energy consumption in most cases. Therefore, both energy codes prescribe at least a maximum WWR in the Baseline model so that any increase in Proposed WWR will need to be offset to maintain compliance. The approach to determining the Baseline WWR varies between the two codes in their current versions beyond having limits, however.

Under 90.1-2019 PRM, the total Baseline model WWR is prescribed if the building type is listed in Table G3.1.1-1. If the building type is *not* listed, the Baseline follows the approach from earlier versions of PRM by matching the Proposed model up to 40%. For this case study, it is an office building with a floor area greater than 50,000 ft^2 and the table prescribes a WWR of 40%.

Under the T24 rules, the Baseline WWR matches the Proposed model up to 40% total and 40% west-facing. The NRACM includes several equations that prescribe how the Baseline WWR must be determined based on the Proposed model.

In a scenario where the building type is not listed in the PRM table and the total and west-facing WWR are less than or equal to 40%, the two sets of rules will provide the same results. Otherwise, the PRM methodology is more stringent for certain building types. T24 is more generally more complicated and is more restrictive for projects with higher ratios of west-facing glazing.

The case study analysis below explores these impacts in greater detail.

CASE STUDY: LONG BEACH OFFICE WWR

The ***Long Beach Office*** case study model is a 4-story office building in Long Beach, California. The project represents a realistic modern office building design, with a mix of enclosed and open office spaces, conference rooms, corridors, a café and typical supporting spaces. The design has a total WWR of about 40% which is the point at which the PRM and T24 rules are the same except for the additional west-facing limit in T24. The ratios per orientation were adjusted to investigate the impact of various ruleset measures in the two standards. This was done by scaling the existing windows larger or smaller using the ”shrink” tool within the simulation software.

Analysis & Results

Many simulations were run to understand the impact of the differences in the rules of the two standards. In general, it was difficult to find a scenario where the west-facing T24 rule led to a significant difference in Baseline model energy consumption compared to the PRM rule which focused on total WWR alone. Two scenarios were provided below that demonstrate an exaggerated, yet reasonable, version of the design to illustrate the impact of the west-facing T24 rule.

Scenario 1 – Total and West WWR > 40%

The first scenario has a total WWR of 49% and a west-facing WWR of 75%, as shown in the table below. Following the PRM rule, the WWR of the Baseline model is scaled down proportionally (i.e. equal percent reduction of glazed area across all façade orientations) until it equals 40%. The T24 rule scales the west façade in greater proportion than the rest so that the west WWR equals 40% and the total equals 40%.

Orientation	Proposed WWR (%)	PRM Baseline WWR (%)	T24 Baseline WWR (%)
North	48.8%	39.6%	51.5%
East	23.9%	19.4%	25.2%
South	48.4%	39.3%	51.1%
West	75.4%	61.3%	40.0%
Total	**49.2%**	**40.0%**	**40.0%**

The two versions of the Baseline model have the same total WWR but different proportions of west-facing glazing versus other orientations. The figure below indicates the following:

- PRM Baseline EUI: 54.6 kBtu/ft^2/yr
- T24 Baseline EUI: 53.98 kBtu/ft^2/yr
- Difference: 1.1%

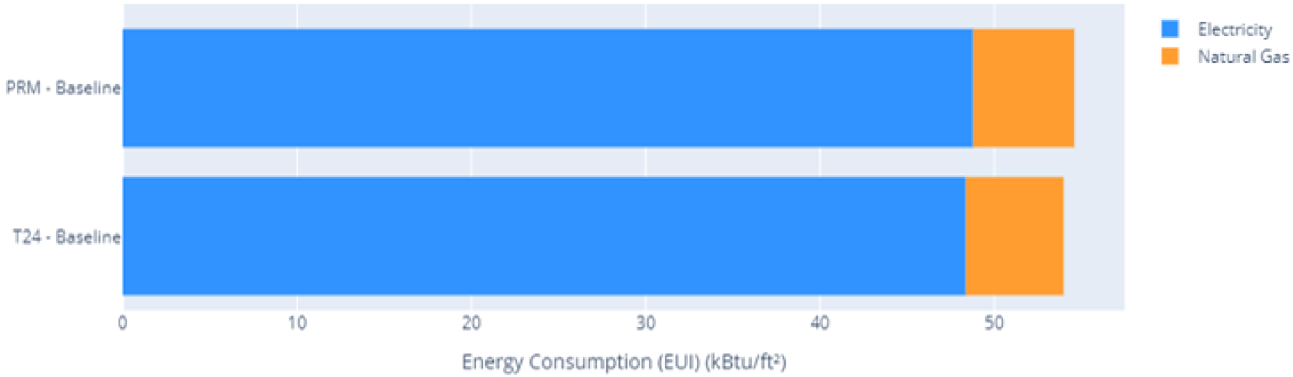


Figure 16: Energy use comparison between the Baseline WWR rules for Scenario 1

The Baseline models both have HVAC systems with AHUs zoned per-floor. West-facing zones typically have the strongest impact on HVAC sizing in California as the cooling peak tends to occur in the afternoon when the ambient temperature is the highest and solar gains in the west facades are strongest. (We assume that is the basis for this additional T24 rule, although were unable to verify that.) The impact, however, was a difference of 0.75% in the peak cooling load between the two Baseline models.

Scenario 2 – West WWR > 40%

The second scenario was selected to demonstrate Baseline models which have different total WWR while also having different proportions of adjustment to west-facing glazing. They are summarized in the table below.

Orientation	Proposed WWR (%)	PRM Baseline WWR (%)	T24 Baseline WWR (%)
North	36.4%	36.4%	36.4%
East	23.9%	23.9%	23.9%
South	30.4%	30.4%	30.4%
West	63.5%	63.5%	40.0%
Total	**39.6%**	**39.6%**	**32.5%**

The results for the analysis of this scenario is shown in the list and figure below:

- PRM Baseline EUI: 54.48 kBtu/ft^2/yr
- T24 Baseline EUI: 53.08 kBtu/ft^2/yr
- Difference: 2.6%

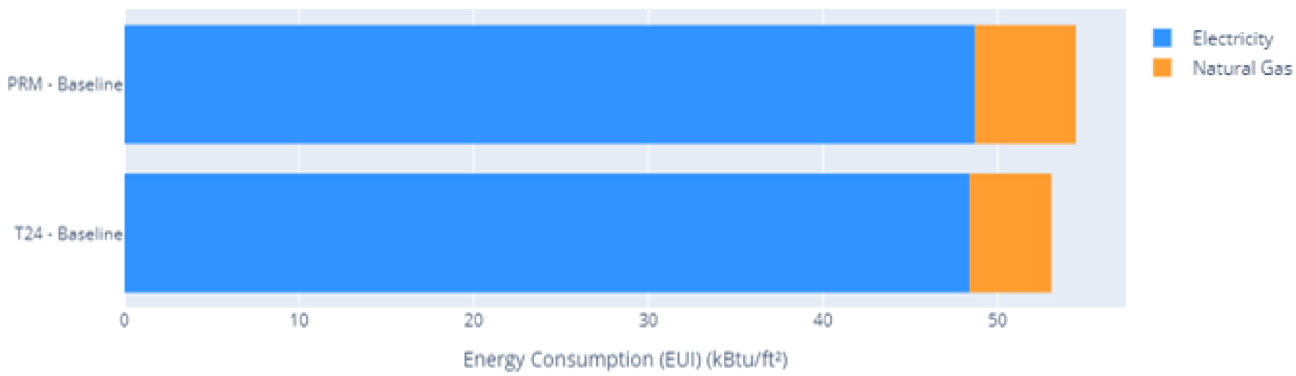


Figure 17: Energy use comparison between the PRM and T24 models for Scenario 2

The percentage change increased compared to the prior scenario, indicating that west-facing glazing does not have a significantly stronger influence on energy use than the other highly glazed facades (east and south).

The difference in peak cooling load between the two Baseline models in the second scenario also increased to 2.3%.

CONCLUSION

The analysis of this case study does not seem to warrant the added complexity of regulating west-facing glazing ratios separate from total. The single case study may not represent all building types and façade designs, further studies could be done to explore other examples.

The benefits of reducing the complexity of a Baseline model that is currently required to be automated may not be worthwhile. However, there have been other CalBEM projects exploring model reviews by 3rd parties which could include non-automated implementation of T24 compliance models. This has occurred in the past with statewide utility incentive programs that allowed T24 models with user-input gains, schedules and setpoints. Reducing the complexity would allow more modelers and BEM tools to implement the Baseline generation rules more easily, and reviewers to check the same.

Measure 5: Lighting in Unconditioned Spaces

Lighting in unconditioned spaces refers to light fixtures illuminating areas that are not conditioned. This is common in most buildings, especially spaces like warehouses, storage rooms, parking garages, and mechanical/electrical rooms.

90.1 PRM does not differentiate between lighting in conditioned and unconditioned spaces, treating all lighting as a “regulated” energy end use and including it in compliance calculations. In contrast, the T24 performance approach allows modeling of this lighting in unconditioned spaces but excludes it from the compliance calculations.

While these light fixtures may not be as important as fixtures in conditioned spaces, compliance modeling already accounts for that importances by modeling the HVAC systems.

The T24 approach to excluding lighting in unconditioned spaces from the compliance results is problematic for the following reasons:

- The approach does not encourage beyond-code lighting wattage reductions or controls improvements, losing out on potential energy and peak load savings.

- This specialized treatment requires additional calculations and documentation which can be extra work and confusing for design teams and reviewers.

The case study analysis below explores these impacts in greater detail using a distribution warehouse with considerable lighting wattage in unconditioned spaces.

CASE STUDY: DISTRIBUTION WAREHOUSE LIGHTING

This ***Distribution Warehouse*** case study model features approximately 5,000 ft^2 of conditioned office space and 500,000 ft^2 of unconditioned warehouse area, with the warehouse serving as the dominant space type. The interior lighting design in the unconditioned warehouse exceeds code requirements, as shown in the table below, and has a significant impact on lighting and overall energy savings.

Space Type	Design/Proposed LPD (W/ft^2)	T24-2019 LPD (W/ft^2)
Commercial/Industrial Storage (Warehouse)	0.174	0.450

An important factor for the case study project is that it pursued certification under the LEED Rating System which uses the PRM approach and therefore encourages savings in this category.

Analysis & Results

When reviewing the results below, consider what would happen if the warehouse project did not pursue aggressive energy savings for achieving the LEED Certification and was only required to comply with T24. That project may not pursue such a low wattage lighting design, which would make the actual design perform more like the T24 LPD version of the Baseline model results ("T24 Baseline" as labeled).

A comparison of the Baseline and Proposed models highlights the significant role of lighting in unconditioned warehouse spaces in total energy consumption. In the Baseline model, lighting in unconditioned spaces constitutes approximately 59% of total energy use, whereas in the Proposed model, it accounts for around 27%.

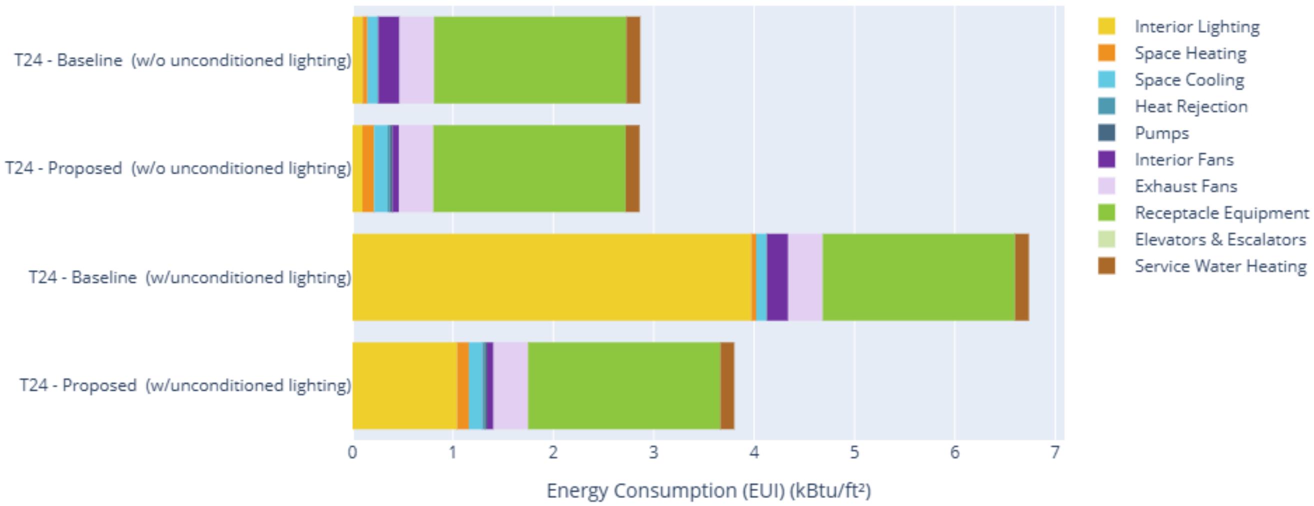


Figure 18: Energy end use comparison with and without lighting in unconditioned spaces.

The graph also underscores the importance of this difference in driving energy savings. Specifically, the energy savings between the Baseline and Proposed models were largely attributed to reductions in lighting energy use in unconditioned spaces, which show a 74% reduction in the Proposed model. For scenarios excluding lighting in unconditioned spaces, the interior lighting energy use remains very similar between the Baseline and Proposed models, reinforcing the critical impact of improvements in unconditioned space lighting on overall energy efficiency.

In a compliance scenario, the key consideration is the margin between the Proposed and Baseline models. The case study results illustrate how including lighting in unconditioned spaces can significantly affect this compliance margin compared to excluding it. As shown in the figure below, the savings between the Baseline and Proposed models increase from 0.3% when lighting in unconditioned spaces is excluded to 44% when it is included.

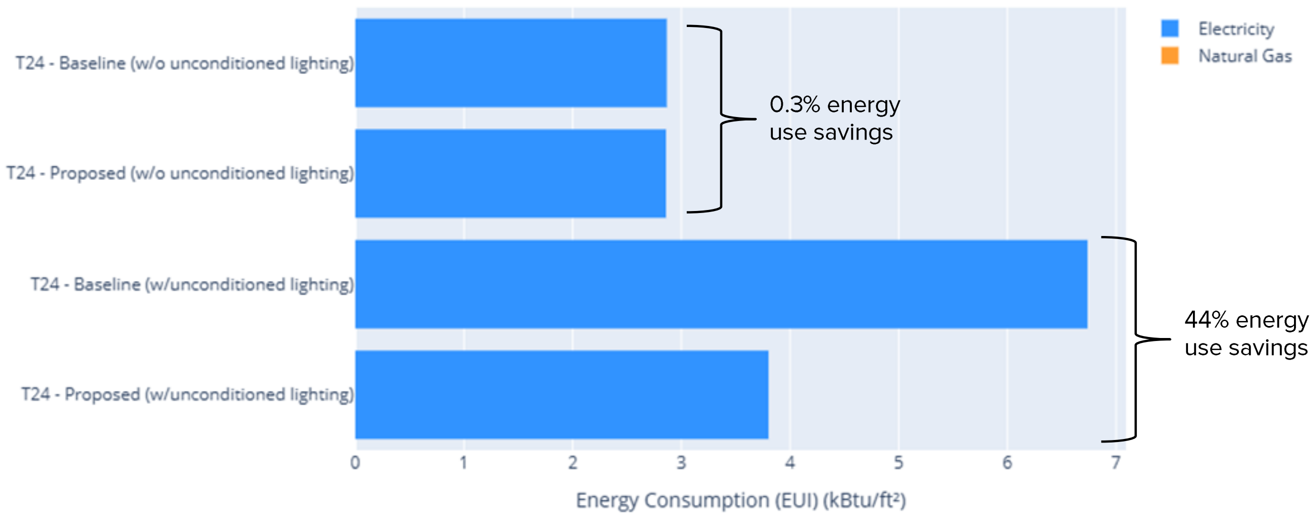


Figure 19: Energy use comparison with and without lighting in unconditioned spaces

CONCLUSION

In conclusion, excluding lighting energy use in unconditioned spaces from compliance calculations leads to an incomplete assessment of "whole-building" performance and misses out on encouraging or requiring beyond-code savings in these spaces.

It is recommended to evaluate including lighting in unconditioned spaces in the T24 compliance results to encourage more real-world savings and make the performance approach more effective.

Additional considerations / further impacts…

Similar results and benefits may also occur with exterior lighting or lighting in any unconditioned spaces – not just warehouse projects.

Measure 6: Natural Ventilation

Natural ventilation uses natural forces like wind and thermal buoyancy to circulate fresh air in a space or building. Such a design strategy can provide ventilation and cooling to keep a space healthy and comfortable in a more energy-efficient manner than circulating air via active mechanical systems. "Mixed-mode" ventilation is a term used for a system that can operate in either mode – natural or mechanical – usually where natural ventilation isn't able to ensure comfort during the entire year. In moderate climates like California, natural or mixed-mode ventilation is a common strategy for low energy building design as it effectively reduces energy use by minimizing HVAC system run-hours, improving indoor air quality, and enhancing thermal comfort.

All modern BEM software tools provide various means of explicitly modeling natural and mixed-mode ventilation strategies. For example, the software used for the analysis on this project, provides a bulk airflow method and also computational fluid dynamics (CFD) to simulate natural ventilation airflow and verify that thermal comfort is met at the level of air particles within a space.

While 90.1 PRM doesn't specify an approach for modeling natural or mixed-model ventilation beyond mentioning its use in schedules, many adopting jurisdictions including the USGBC LEED Rating System, allow projects to claim credit for its use – whether explicitly or through an additional simulation and narrative. T24, on the other hand, permits the use of natural/mixed-mode ventilation only for hotel/motel guest rooms through the specification of an additional hourly schedule.

The T24 approach is restrictive for the following reason:

- Natural or mixed-mode ventilation design strategies cannot be modeled appropriately within the T24 software. These building models often misrepresent HVAC loads and energy use, resulting in compliance penalties and/or are unable to receive credit for their energy efficient design strategies.

The case study analysis described below provides more details about these impacts.

CASE STUDY: CULVER CITY OFFICE MMNV

This ***Culver City Office*** case study model is a new 3-story core & shell office construction in Los Angeles, California. The building features a Mixed-Mode Natural Ventilation (MMNV) system integrated with a Dedicated Outdoor Air System (DOAS) for ventilation and Variable Refrigerant Flow (VRF) system for heating and cooling. The combination of these systems was provided to maximize the ability to turn off heating and cooling systems when they are not needed. Operable windows were incorporated as a key design element, allowing occupants to take advantage of natural ventilation during favorable weather conditions, further reducing reliance on mechanical systems. This hybrid approach demonstrates an effective balance between sustainability and functionality in a modern office setting.

It should be noted that some jurisdictions that adopt energy modeling pathways only allow credit for natural or mixed-mode ventilation if the system is completely automated. While this particular project relied on occupants to open and close windows instead of an automated motorized solution, the modeling methods and estimated energy impacts could apply to either scenario.

Analysis & Results

Comparing the Design / PRM Proposed model with the alternate version without MMNV ("T24 Proposed"), highlights differences in HVAC related energy end-use categories.

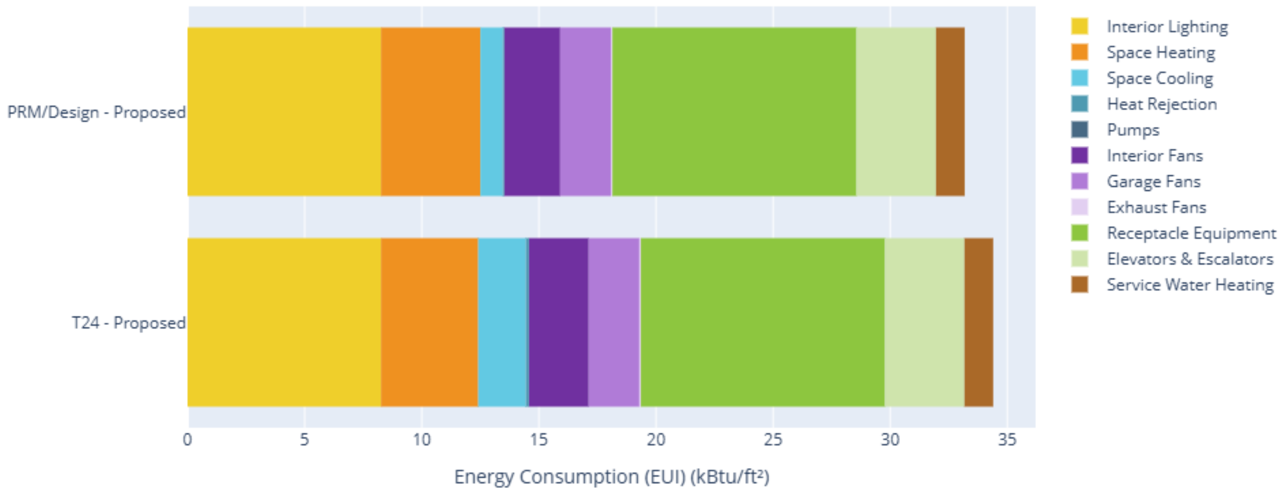


Figure 20: Energy end-use comparison and the impact of MMNV in proposed models

The results in Figure 20: Energy end-use comparison and the impact of MMNV in proposed models highlight key differences in the T24 Proposed model compared to the 90.1 PRM model, primarily due to the inability to model MMNV in T24:

- 103% increase in space cooling & heat rejection, and
- 7% increase in interior (HVAC) fans.

These differences lead to an overall 3.6% increase in whole building energy consumption in the T24 Proposed model. While this may seem modest, the savings potential could be much higher in other parts of California with similarly mild climate. Furthermore, the realized savings were less for this project due to the configuration of the HVAC systems. The DOAS unit provided ventilation air in a decoupled manner from the VRF fan coil units (FCUs). This allowed the FCUs to cycle off when the zone did not need heating or cooling. A traditional VAV system often found in office buildings would likely use more energy to cool and a MMNV strategy would yield greater savings.

CONCLUSION

The limitation of the T24 software to simulate natural and mixed-mode ventilation for buildings and spaces other than hotel/motel guest rooms works against California's goals for energy-efficient, low-carbon and resilient buildings. Also, operable windows and associated motorized controls increase first costs and may be reconsidered on a project that struggles to meet T24 compliance while trying to maintain a budget.

Since the T24 NRACM already permits these strategies for one specific space type, it is recommended to extend this rule to all other building and space types. The modeling methodology is available in at least one approved T24 software tool, and it is in the engine used in the State-developed software already. This change would encourage the use of natural and mixed-mode ventilation in new buildings, extending its benefits to more building types within the state.

Measure 7: Performance Curves: Chiller

Performance curves are used in energy modeling software to represent the capacity and efficiency of equipment across a range of conditions. There are various generic performance curves that have been developed from research in and outside of California and are used in most modern BEM tools. The curves may also be derived for specific equipment models and configurations using regression equations based on a set of manufacturer-provided data. To see example of freely available tools, refer to the following links provided by Integrated Environmental Solutions (IES):

- Water-Cooled Chiller Curve Coefficients Spreadsheet (IP) (link), and
- Air-Cooled Chiller Curve Coefficients Spreadsheet (IP) (link).

The PRM approach allows modelers to align performance curves with the design, using manufacturer-provided data specific to the equipment designed or specified in the drawings. In contrast, T24 prescribes the performance curves given the chiller capacity and type. A separate set of curves are provided for “Path A” and “Path B” chillers. The curve is determined by comparing software inputs of full-load efficiency and integrated part-load value with the requirements of standards.

The T24 approach is restrictive for the following reason:

- Prescribed curves in T24 may not accurately reflect the performance of specified chillers in the design, leading to over- or under-estimation of cooling energy usage.

The case study analysis described below provides more details about these impacts.

CASE STUDY: LIFE SCIENCES OFFICE / LAB CHILLER CURVE

This ***Life Sciences Office/Lab*** case study model is a new 3-building construction for a life sciences program in the San Francisco Bay Area, California. The buildings are designed as core & shell, with 50% of their area dedicated to labs and 50% to offices.

The original heating and cooling plant designs used different types of air- and water-source equipment as well as condenser water loop heat recovery. However, this equipment could not be modeled explicitly and would be too complicated for a comparison of performance curves like this measure analysis pursued.

As part of this exercise, the chiller plant has been modified and split into two versions that were developed to demonstrate the difference in air- and water-cooled chiller performance curves, respectively. These are described in greater detail in the Analysis & Results section below.

Analysis & Results

Scenario 1: Air-cooled Chillers

The modified chiller plant for the first scenario utilized a single air-cooled chiller modeled in each of the three plants (one for each of three buildings). While it would be more realistic for the plant to have multiple chillers staged, a single chiller was used intentionally to focus on the difference of the curve set rather than the staging assumptions. The Design/PRM Proposed chiller data was an air-cooled unit with multiple variable-speed scroll compressors based on a selection from another project, and performance curves were generated from detailed manufacturer data referencing the previously linked spreadsheet. The T24 chiller performance curve set was from the NRACM Appendix 5.7 spreadsheet file with the “Curve Identifier” of “Air-Cooled Scroll”. In both cases, three separate curves were used:

- one adjusting capacity as a function of temperatures,
- one adjusting efficiency as a function of the same temperatures, and
- another adjusting efficiency as a function of part-load ratio.

The graph in Figure 21 below illustrates the efficiency (COP) against part-load ratio based on simulation results for the two curve sets. The result is a higher operating efficiency based on the custom performance curves for the real chiller as compared to the prescribed T24 scroll chiller.

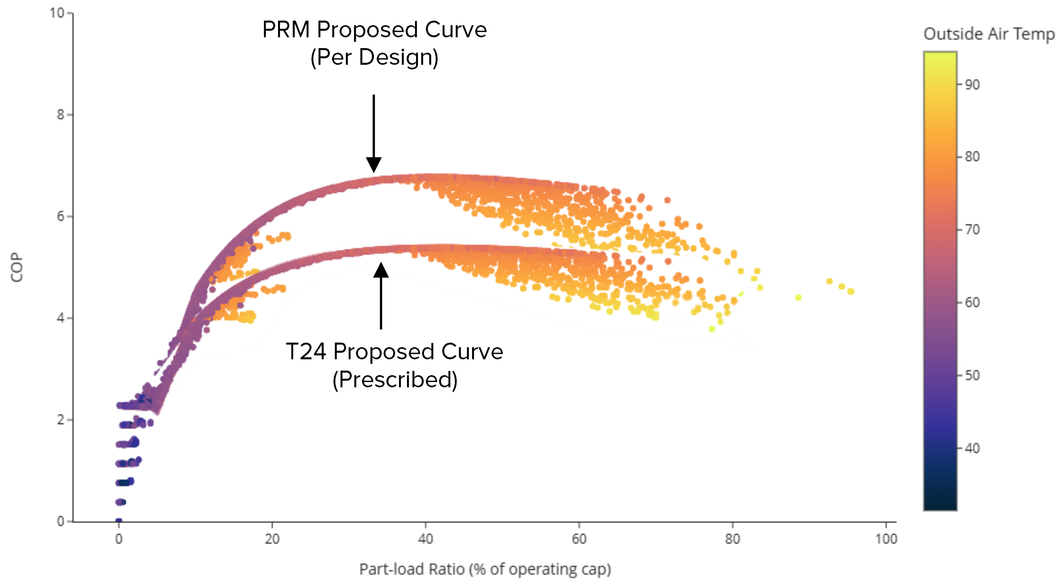


Figure 21: Comparison of COP vs. Part-Load Ratio and ambient temperature for air-cooled chillers in proposed models

The whole-building energy results are shown in Figure 22 below, indicating the following when replacing the design curve set with the applicable T24 curves:

- Space cooling energy increase: 23% (14.36 → 17.61 kBtu/ft^2/yr), and
- Whole-building energy increase: 2.4% (139.09 → 142.41 kBtu/ft^2/yr).

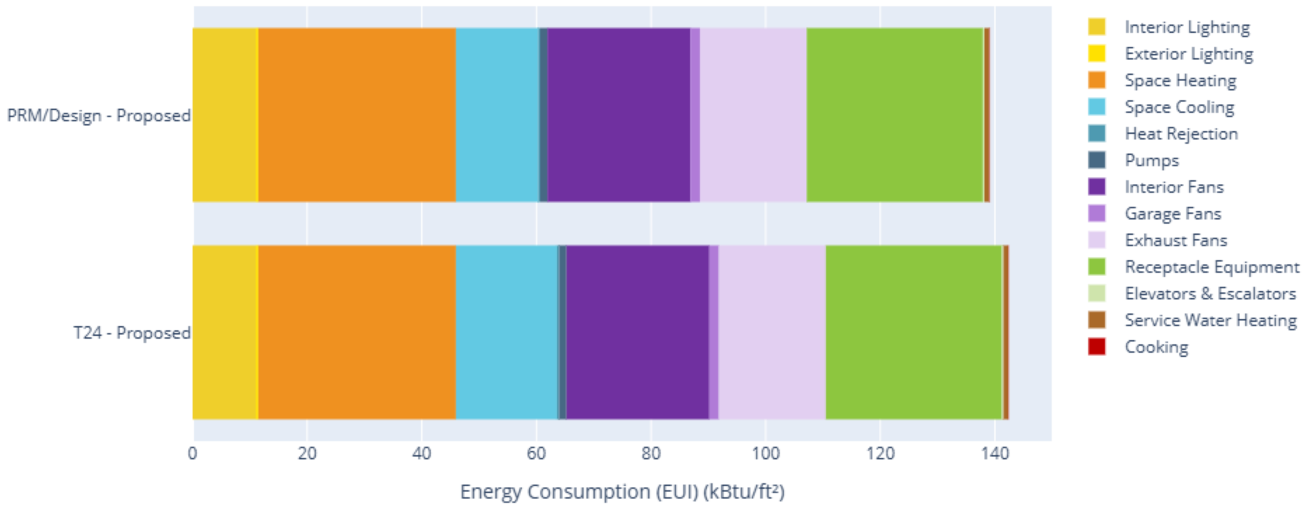


Figure 22: Energy end-use comparison for air-cooled chillers in proposed models

Scenario 2: Water-cooled Chillers

The approach to evaluating the water-cooled chillers was similar to the air-cooled approach with the below exceptions:

- The temperature adjustments use condenser water temperature instead of outdoor temperature.

- The design/PRM Proposed curves were based on a water-cooled, variable-speed screw chiller selection from a project and the water-cooled version of the previously linked spreadsheet.
- The T24 chiller is based on the curve set for the Water-cooled positive displacement "Path A" chiller.

Similarly to Scenario 1, the graph in Figure 23 below illustrates the T24 curves with a reduced efficiency at lower temperatures as well. Note that the plot color codes the points based on outside air temperature, although that is not directly relevant to water-cooled chillers.

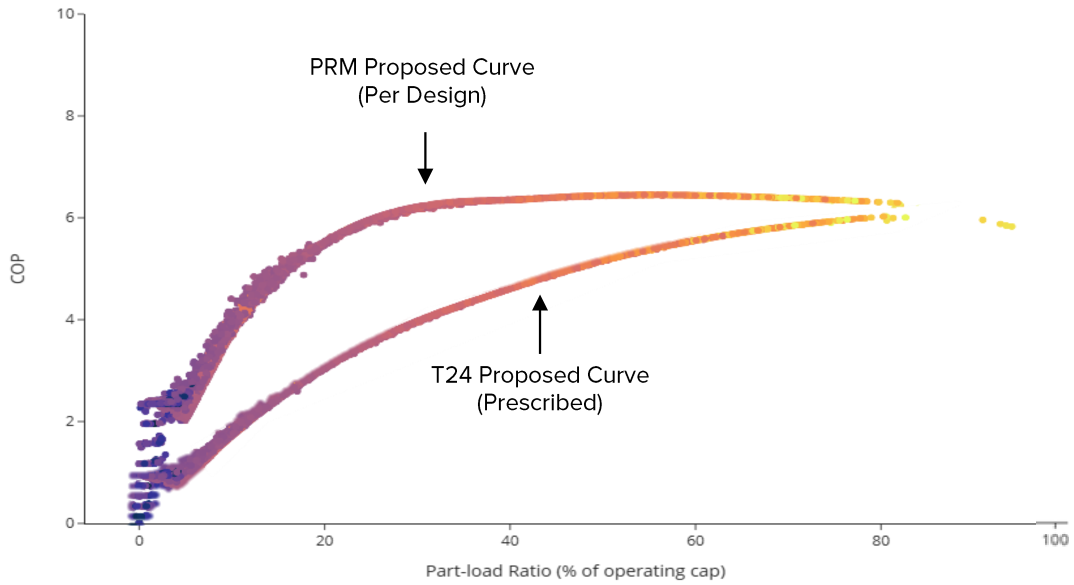


Figure 23: Comparison of COP vs. Part-Load Ratio and ambient temperature for water-cooled chillers in proposed models

The whole-building energy results for the water-cooled chiller comparison are shown in Figure 24 below, indicating the following when replacing the design curve set with the applicable T24 curves:

- Space cooling energy increase: 33% (16.01 → 21.33 kBtu/ft^2/yr), and
- Whole-building energy increase: 3.7% (142.19 → 147.46 kBtu/ft^2/yr).

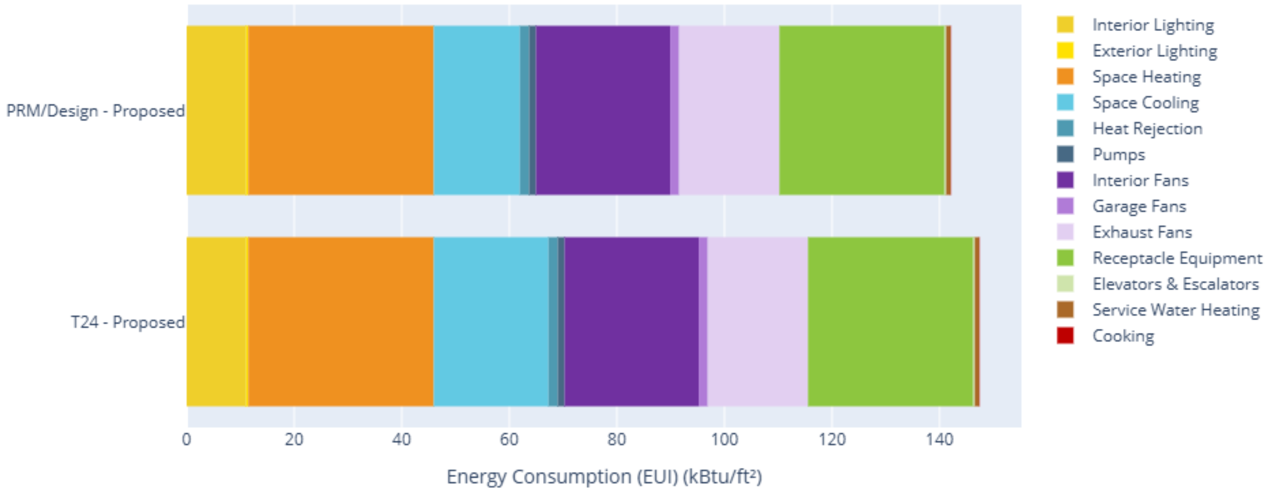


Figure 24: Energy end-use comparison for water-cooled chillers in proposed models

The results in Figure 22 and Figure 24 show that space cooling and heat rejection energy use in the T24 Proposed models increase by 23% for air-cooled chillers and 30% for water-cooled chillers compared to the Design / PRM Proposed models. These increases are due to differences in the performance curves for the respective chiller types.

The whole-building energy use trend is the same, with percentages that are around 2-4%. This difference can be more significant for a project that operates in part load conditions (i.e. does not have higher EPDs and laboratory ventilation rates like the case study model). Furthermore, the heating energy of the actual project is much less than what the case study model indicates due to the simplified heating plant without the condenser water heat recovery.

CONCLUSION

This case study highlights how actual chiller performance can vary from the assumed performance in the prescribed T24 curve sets. This work also exposes how limited the NRACM inputs are related to waterside plants and equipment. The following considerations are recommendations for future T24 development:

1. Consider updating the default chiller curve sets with a range of curve sets taken from actual chillers to ensure the curve sets are relevant and suitable. This may lead to adjusting existing curves or creating additional options to reflect the array of technologies.
2. Consider allowing user-input performance data so that the benefits of high-performance design strategies and efficient equipment selections may be realized in T24 compliance.
3. Incorporate software capabilities of common waterside plant design such as staging strategy of chillers and other equipment that will allow for better representation of the actual operation of the plant.

This is more important now than ever as there is more pressure on design teams to meet T24 energy performance requirements. Much of this work falls on the HVAC design team, and much can be gained from fine-tuning system selections and control sequences.

Additional considerations / further impacts…

Similar prescribed curves in T24 apply to other types of equipment such as DX cooling systems, heat pumps and VRF systems. The limited list of performance curves restricts building projects that would like to demonstrate compliance from purchasing a more efficient equipment.

Measure 8: Climate Zones

Climate zones (CZs) represent geographic regions with similar weather conditions like temperature, humidity, and precipitation. They are used in energy codes and standards to set minimum envelope performance criteria or HVAC requirements like airside economizer high limits. Climate zones are not typically relevant to design practice outside of the application of the codes and standards which adopt them.

DOE/ASHRAE defines the climate zones used in 90.1 PRM. They are determined based on statistical analysis of typical weather data which is updated every few years. For the United States, a total of nine (9) main climate zones and are published in lookup tables by county in ASHRAE Standard 169 and are published for each county.

California's Title 24 climate zones were established by the California Energy Commission in the late 1970's to standardize energy efficiency calculations. Today there are sixteen (16) California climate zones (CA-CZs) across the state, as shown separated by black boundaries in the image below. California is served by (7) different ASHRAE climate zones as it is illustrated below in overlapping colored areas, although most of the state is covered by CZ 3B and 3C.

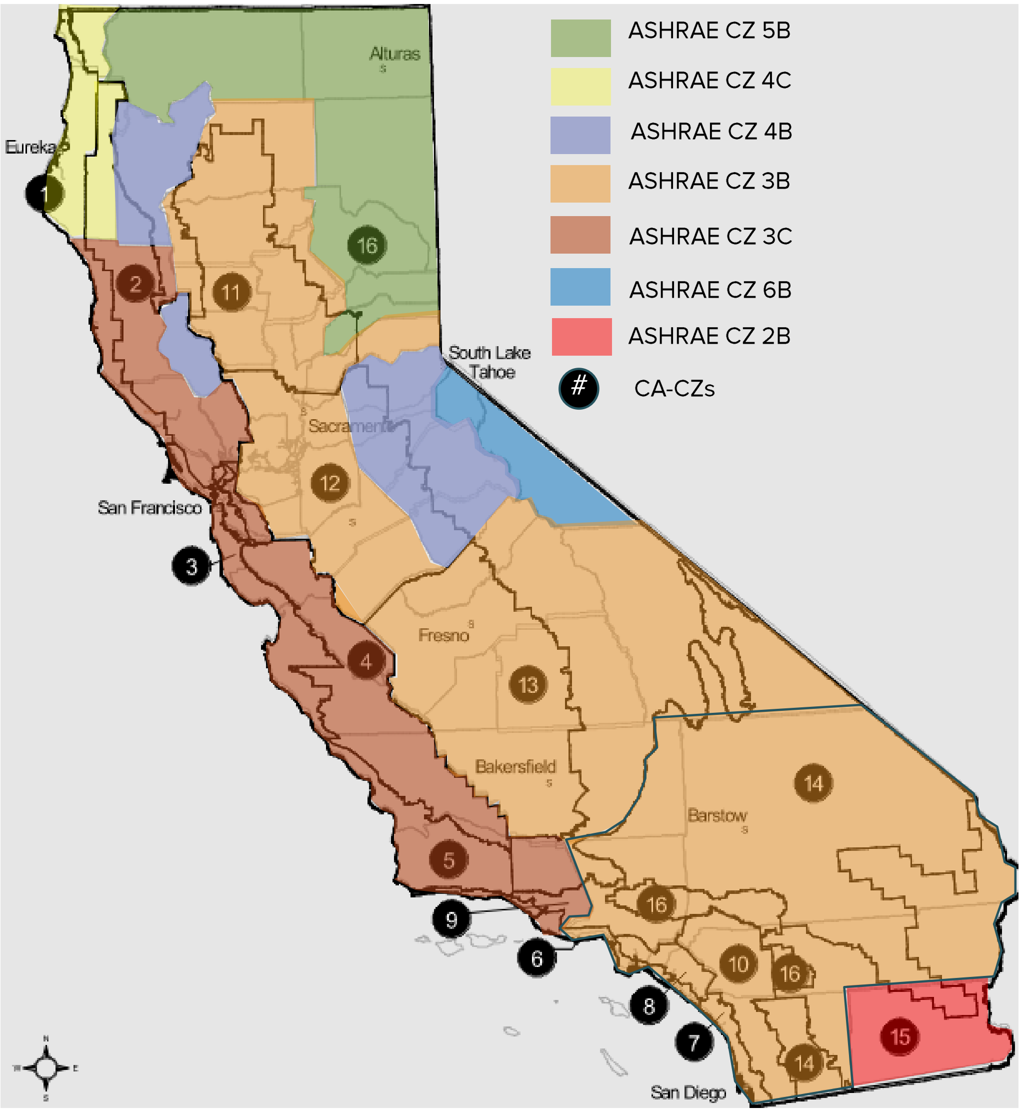


Figure 25: ASHRAE and T24 Climate Zones in California

This measure is unique compared to the rest in this report. Instead of focusing on aspects of T24 compliance that may not adequately represent an actual design, this measure investigates whether the vast number of the California climate zones adds value to the analysis. Reducing the number of zones or adopting the ASHRAE climate zones could yield several benefits in the practical use of Title 24 and the development of future code updates.

The case study analysis described below provides more details about the impacts of varying envelope requirements for CA-CZs.

Case Study: Long Beach Office

This case study analysis uses the ***Long Beach Office*** model. The model was used to evaluate the energy impact of varying envelope performance values between similar California climate zones (CA-CZs).

The table below presents the prescriptive envelope requirements (U-factors) for each component type, as specified for T24 baseline models, along with the area-weighted average U-factor specific to this case study. The color fill of the U-factors shows the variation across component types (i.e. rows in the table).

Envelope Component: Type	CA-CZs																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	16	16
Roofs/Ceilings: Wood Framed & Other	0.034	0.034	0.034	0.034	0.034	0.049	0.049	0.049	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
Walls: Metal-framed	0.069	0.062	0.082	0.062	0.062	0.069	0.069	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062	0.062
Floors/soffits: Other	0.048	0.039	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.071	0.039	0.071	0.071	0.039	0.039	0.039	0.039	0.039
Fenestration: Curtainwall/Storefront	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410	0.410
Ground contact Floor	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020

Many CA-CZs share identical or similar envelope requirements, resulting in a maximum variation of only 6–7% in the area-weighted average U-factor for this model. Several CA-CZs could be combined into a single ASHRAE climate zone without compromising unique envelope performance requirements. For example, ASHRAE CZ-3C corresponds closely to 4 different CA-CZs: 2, 3, 4, and 6. Each of the four CA-CZs have varying envelope requirements under T24 as seen from the table above. The analysis evaluates the difference in energy use between these 4 sets of envelope requirements using a single model and fixed weather file.

Analysis & Results

The graph below illustrates the energy impact of varying prescriptive envelope requirements in the T24 Baseline models for CA-CZs 2, 3, 4, and 6, alongside their respective energy savings compared to the 24 Proposed model. The difference between the two extremes in EUI terms is 0.74 kBtu/ft^2/yr or 1.4%, which is considered minimal.

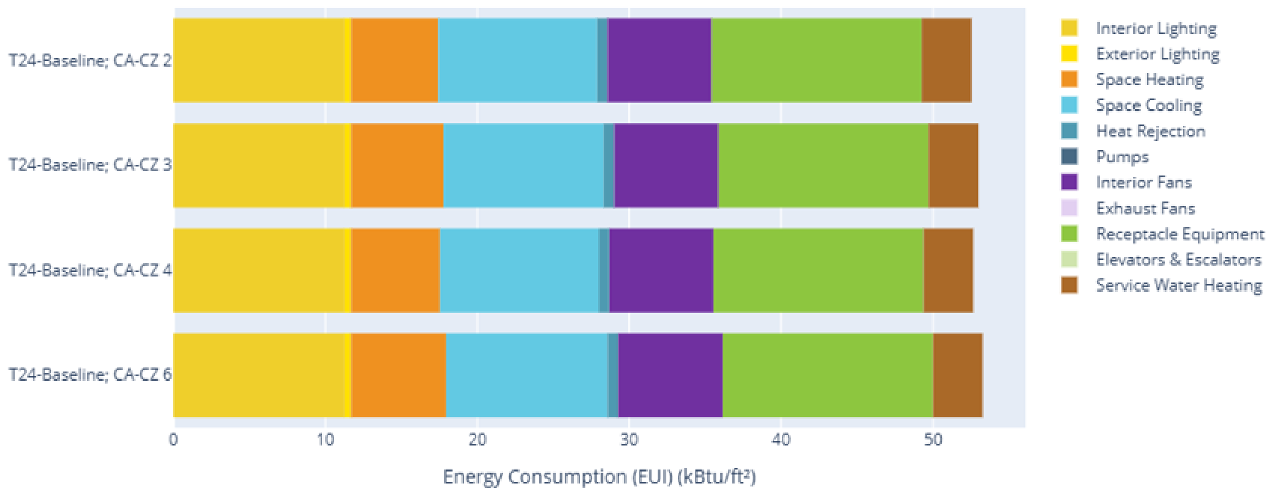


Figure 26: Energy end-use comparison across CA-CZs 2, 3, 4, and 6 due to varying envelope requirements

CONCLUSION

This analysis focused on one group of California climate zones which could be mapped to a single ASHRAE climate zone: 3B. The analysis showed that the difference in energy use was very small compared to the variations caused by the limitations of the software or the restrictions of the code rulesets found in many other areas of the compliance modeling process. While this is a limited study, it is presented to show an area where simplicity could benefit the T24 code. The advantages of this could include the following:

1. Fewer climate zones would result in smaller, simpler tables in the code, fewer iterations of analysis required during research for codes and standards updates, and related simplifications.

2. California's T24 code could leverage ASHRAE's existing work and updates that happen every few years without the need of independent studies. Existing research and methods developed to evaluate updates to ASHRAE 90.1 or the IECC energy codes can also be leveraged.

Based on the initial findings above, a consolidation of the California Climate Zones should be evaluated.

Conclusion

While each of the case study evaluations for each measure include their own specific conclusions, a few common themes stand out. These are summarized below.

Prescribing Values Introduces Error

The constrained input options in T24 compliance modeling exist, presumably, with the intent of ensuring accuracy. However, there are many cases where this constraint introduces inaccuracy. This was found in the following case study analyses:

- Prescribed equipment power density (EPD) led a 6% error based on whole-building EUI.
- Prescribed heating / cooling setpoints led to an error of 3.4% (10% in cooling) in the first case study and caused unmet load hours and a greater error in the second case study.
- Prescribed and overridden schedules led to an error of 43% for the case study model.
- Lack of natural and mixed-mode ventilation simulation capabilities (other than in hotel/motel guestrooms which are uncommon) led to an error of 3% for the case study model.
- Prescribed chiller performance curves led to an error of up to 4%.

Most of these studies introduced reasons why projects would see even further increases in error. The extent of this error could be the focus of another assessment like this one to help quantify the error margins or prioritize solutions across them. This project sought to provide realistic models out of a subset of available projects. Even so, many of these errors could be compounded on a single project.

Two potential solutions could be explored:

1. **Allow user-input values**. Allowing user-inputs would help to resolve issues with items like EPDs, setpoints and schedules. This could be done in a way that flags these inputs if they vary from default values (or from within a percentage of defaults) and require a narrative explanation of some sort. This solution could also work for performance curves and natural ventilation controls; however, these would require significantly more research and development to align with the extent of definition in software and the ACM that currently exists. Alternatively, projects could opt for an **optional 3rd party review** by qualified professionals to check modeled items that don't exist in the ACM.
2. **Relax the complexity and attempted accuracy of compliance modeling**. The current compliance software is very detailed and complex with the assumed goal of "accuracy" of compliance models. However, the rules do not allow accuracy with respect to actual operations and energy performance (and intentionally avoid it). Therefore, the performance approach could evolve to use simpler methods of evaluating energy compliance. This could be done in various ways, like by specifying a building geometry and HVAC system type and letting the software build and auto-size the HVAC components. The goal would be something closer to an asset rating of the building or subsystems rather than an annual energy result.

These two solutions could be evaluated in parallel and could potentially work together. For example, by adapting the current State-provided software tool to a simplified version, and introducing a more flexible version which could be reviewed by specialized professionals. The latter approach would cost more to review, but these costs may be worth it for larger projects with more progressive systems and operational requirements.

Complexity May Not Be Worthwhile

The takeaway from a few of the measures did not impact accuracy in the same sense. Instead, they evaluated whether the added complexity was impacting the compliance results. These measures included:

- 16 California Climate Zones – The impact on energy use due to combining several California CZs into a single ASHRAE CZ had an impact of less than ± 1% on energy use. If that trend remains similar across the state, California could adopt the ASHRAE CZs without risking much in the way of energy use. The benefits of leveraging another existing climate standard could be significant to California.
- Baseline West-facing WWR - This additional requirement adds complexity that does not appear to be warranted. Eliminating it could simplify the performance compliance ruleset.

Schedule-Specific Issues

While some aspects of schedule-related issues were described in the first subsection above, there is another aspect that should be evaluated in parallel:

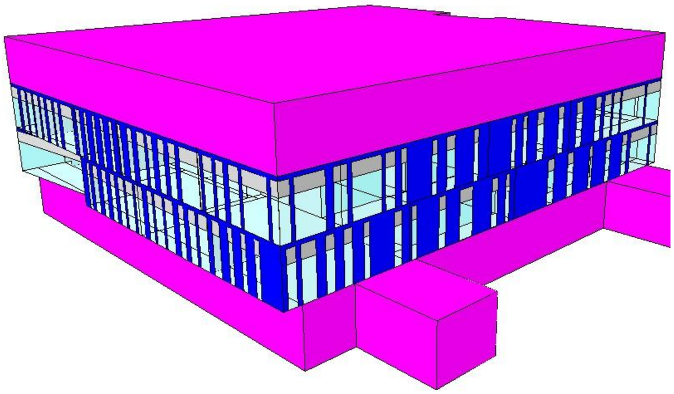
- Eliminate the multi-floor AHU override schedule rules. This introduces significant error and deviates from the intent of keeping schedules equal in the Proposed and Baseline models.

Missed Opportunity

Treating lighting in unconditioned spaces (and exterior lighting) as outside of the compliance result is a missed opportunity. By including these end-use categories in compliance, it would encourage beyond-code lighting designs and could drive innovation in design and the application of technology in certain spaces and buildings.

Appendix A. Case Study Models

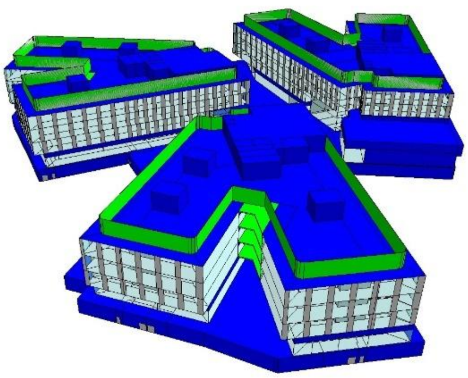
Office and Operations Center

Location	San Francisco, CA
Images	
Description	2-story office building with integrated operations center. Operations center has spaces with high equipment power densities than typical office building.
HVAC System	Air-side: CHW Fan Coil Units for computer rooms, HW & CHW VAV Reheat for all other spaces Water-side: Air-to-Water Heat Pump for Hot Water. Water-Cooled Chillers for Chilled Water
Gross Floor Area (ft²)	42,833
Window to Wall Ratio (%)	35
Space Count	101
Occupant Density (ft²/person)	85
Lighting Power Density (W/ft²)	0.57
Equipment Power Density (W/ft²)	2.5
Heating Setpoint (°F)	70
Cooling Setpoint (°F)	75
Outdoor Air Flow Rate (CFM/ft²)	0.21
ASHRAE Standard 90.1 Version	90.1-2010
Other Notes	The reported EPDs are inclusive of diversity factors per design.

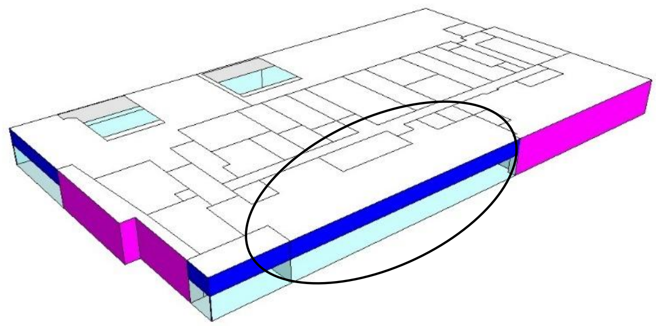
Long Beach Office

Location	Long Beach, CA
Images	
Description	4-story office building primarily composed of open and enclosed offices, conference rooms, a café and other supporting spaces typical of an office building.
HVAC System	Air-side: Dedicated Outdoor Air System (DOAS) with DX Cooling to provide tempered ventilation air, and Air-Source Variable Refrigerant Flow (VRF) for heating and cooling.
Gross Floor Area (ft^2)	104,265
Window to Wall Ratio (%)	40
Space Count	144
Occupant Density (ft^2/person)	79
Lighting Power Density (W/ft^2)	0.72
Equipment Power Density (W/ft^2)	1.33
Heating Setpoint (°F)	70
Cooling Setpoint (°F)	75
Outdoor Air Flow Rate (CFM/ft^2)	0.21
ASHRAE Standard 90.1 Version	90.1-2019
Other Notes	The building orientation was modified from the original design for the WWR analysis by rotating the project 270° clockwise. The glazing design was driven by site conditions, not solar orientation, and it supported the study to have the higher-glazed facades in the east, south and west orientations. The north façade (not shown in the image above) has the least glazing in the case study model.

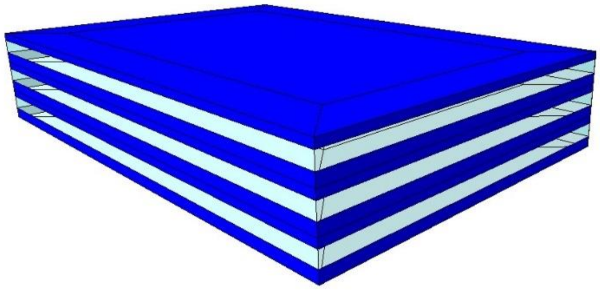
Life Sciences Office/Lab

Location	San Francisco Bay Area, CA
Images	
Description	(3) 4-story core & shell buildings designed for 50% laboratory and 50% office spaces supporting a life science program. Approximately 70% of gross floor area is future tenant space and 30% is supporting spaces like lobbies, electrical, mechanical, dining, fitness, etc.
HVAC System	Air-side: VAV Reheat – AHUs with hot & chilled water + hot water reheat terminal units. Water-side: Identical heating & cooling plants in each building: (2) water-cooled chillers, (4) water-source heat pumps and (2) air-source heat pumps providing hot water, condenser water heat recovery and (2) open cooling towers.
Gross Floor Area (ft²)	555,434
Window to Wall Ratio (%)	45
Space Count	519
Occupant Density (ft²/person)	165
Lighting Power Density (W/ft²)	0.48
Equipment Power Density (W/ft²)	1.43
Heating Setpoint (°F)	70
Cooling Setpoint (°F)	72
Outdoor Air Flow Rate (CFM/ft²)	0.14
ASHRAE Standard 90.1 Version	90.1-2010
Other Notes	For Chiller Performance Curves measure, the plants were modified to more clearly demonstrate the difference in chiller performance curves. See more details in measure section.

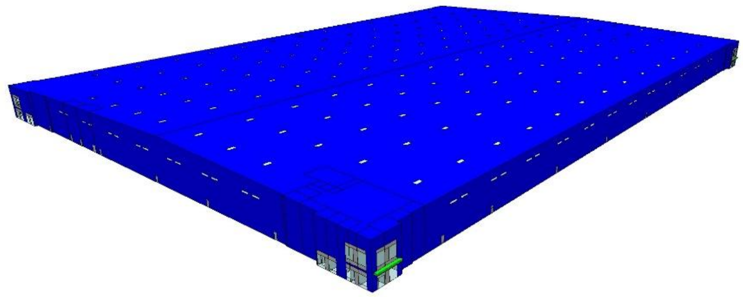
Commercial Kitchen

Location	Los Angeles, CA
Images	
Description	Commercial kitchen in a 20-story office building. The kitchen space is designed for relaxed temperature setpoints.
HVAC System	Air-side: Single-zone make-up air unit with HW & CHW coils and, kitchen air purification unit Water-side: Condensing Boilers for Hot Water; Water-Cooled Chillers for Chilled Water
Gross Floor Area (ft^2)	2,590
Window to Wall Ratio (%)	57
Space Count	1
Occupant Density (ft^2/person)	150
Lighting Power Density (W/ft^2)	0.95
Equipment Power Density (W/ft^2)	1.5
Heating Setpoint (°F)	65
Cooling Setpoint (°F)	85
Outdoor Air Flow Rate (CFM/ft^2)	Exhaust driven ventilation at 3.8 CFM/ft^2
ASHRAE Standard 90.1 Version	90.1-2010
Other Notes	The kitchen includes cooking loads modeled at 5.14 W/ft^2 for natural gas and 3 W/ft^2 for electricity.

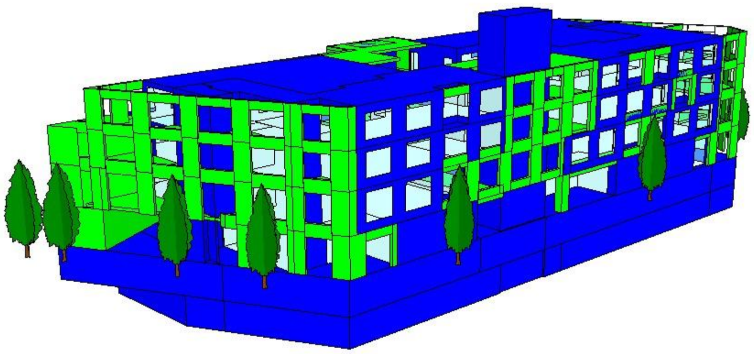
Simple Office Building

Location	Long Beach, CA
Images	
Description	3-story office building, mainly with conference rooms on the first floor and offices on the second and third floors. *Not a real project. Simple model used to more easily demonstrate complicated T24 schedule issues.
HVAC System	Air-side: VAV Reheat w/ HW heating and DX Cooling. AHUs zoned by orientation. Water-side: Boilers for Hot Water
Gross Floor Area (ft²)	53,660
Window to Wall Ratio (%)	43
Space Count	15
Occupant Density (ft²/person)	126
Lighting Power Density (W/ft²)	0.92
Equipment Power Density (W/ft²)	1.3
Heating Setpoint (°F)	70
Cooling Setpoint (°F)	75
Outdoor Air Flow Rate (CFM/ft²)	0.11
ASHRAE Standard 90.1 Version	90.1-2019
Other Notes	-

Distribution Warehouse

Location	Central Valley, CA
Images	
Description	500,000 ft^2 of unconditioned warehouse with 5,000 ft^2 of conditioned office space.
HVAC System	Air-side: Energy Recovery Ventilator with Air-Source Variable Refrigeration Flow.
Gross Floor Area (excl. garage) ft^2	505,000
Window to Wall Ratio (%)	3.5
Space Count	19
Occupant Density (ft^2/person)	91
Lighting Power Density (W/ft^2)	0.18
Equipment Power Density (W/ft^2)	0.22
Heating Setpoint (°F)	70 (conditioned office)
Cooling Setpoint (°F)	74 (conditioned office)
Outdoor Air Flow Rate (CFM/ft^2)	0.23 (conditioned office)
ASHRAE Standard 90.1 Version	90.1-2010
Other Notes	-

Culver City Office

Location	Los Angeles, CA
Images	
Description	3-story warm shell & core office building
HVAC System	Air-side: Mixed-Mode Natural Ventilation (MMNV) within a Dedicated Outdoor Air System featuring DX Cooling and heat pump heating, with Variable Refrigerant Flow, using operable windows.
Gross Floor Area (excl. garage) ft^2	44,040
Window to Wall Ratio (%)	32
Space Count	45
Occupant Density (ft^2/person)	312
Lighting Power Density (W/ft^2)	0.35
Equipment Power Density (W/ft^2)	0.46
Heating Setpoint (°F)	69
Cooling Setpoint (°F)	75
Outdoor Air Flow Rate (CFM/ft^2)	0.19
ASHRAE Standard 90.1 Version	90.1-2010
Other Notes	-

Appendix B. Non-Selected Measures

The measures below were considered for evaluation in this project. However, with insufficient time to evaluate every measure, these measures were deemed a lower priority and omitted from assessment. They may be worth studying in future projects or considering in future codes and standards development work.

#	Measure Name	Design Model Inputs	90.1 PRM Rule	T24 NRACM Rule
x0	Performance curves: AAHP w/ variable speed compressor	It's common for modern heat pumps and DX cooling equipment to have variable speed or inverter-driven compressors which provide turn-down and improved efficiency at reduced part-load.	Not specifically addressed	NRACM prescribes performance curves and limits efficiency features.
x1	Unmet load hours	Per simulation results and comparison against cooling/heating setpoints	Per 90.1 section G3.1.2.3, "unmet load hours for the proposed design or baseline building design shall not exceed 300 (of the 8760 hours simulated)."	Per ACM section 2.4, "throttling range is fixed at 2 F and a cooling setpoint of 75°F results in an acceptable temperature band of 74°F to 76°F. Furthermore, no zone is allowed to have UMLH exceeds 150 hours"
x2	Geometry Floor Plan Boundary	No specific rules. Common practice is often center-lines of all walls (more accurate for modeling 1-dimensional heat transfer through walls at corners).	"Floor area, gross" is defined similarly to ACM; however, PRM does not reference this definition – just that Baseline model shall have "identical conditioned floor area as the proposed design."	Per ACM section 5.4.1, "Area shall be measured to the outside of exterior walls and to the center line of partitions."
x3	Building Area Method	N/A	Can be used where design is not complete (e.g. core & shell buildings).	This method is not included in the ACM. Core & shell buildings can be modeled, but must select space function rather than building area method.

x4	Electrochromic Glass	Modeled based on glazing product performance data provided by the manufacturer	Per Table G3.1.5.a, "all components of the building envelope in the proposed design shall be modeled as shown on architectural drawings or as built for existing building envelopes"	Per ACM section 2.1.4, "Building features or systems not covered in this manual must apply for approval via the exceptional calculation method to the Energy Commission". Lack of instructions on exceptional calculation procedure
x5	Central Air-to-Water Heat Pump	Air-to-water heat pump modeled based on mechanical schedule and manufacturer data. The equipment provides heating hot water to AHU heating coils, VAV reheat coils, etc	Not specifically addressed in 90.1. Air-to-water heat pump modeled based on mechanical schedule and manufacturer data	Equipment not covered in ACM. CBECC-Com (or CBECC for 2022 code cycle) does not have the capability to model central air-to-water heat pump. Only electric resistance boiler is available.
x6	Fan / Pump Power	Fan/pump input power is determined based on BHP and motor efficiency input. BHP modeled per mechanical schedule. Motor efficiency is determined based on the next standard size motor horsepower	Per Table G3.1.5, "where an HVAC system has been designed and submitted with design documents, the HVAC model shall be consistent with design documents"	Per ACM section 5.7.3.2, "the user entered brake horsepower for the proposed design is compared against the next smaller motor size from the user entered supply fan motor horsepower. The proposed design supply fan brake horsepower (bhp) is set to the maximum of the user entered bhp and 95 percent of the next smaller motor horsepower"
x7	Condenser Water Pump Speed	High efficiency variable speed condenser water pump per mechanical schedule	Not specifically addressed in 90.1. Modeled per mechanical schedule	Per ACM section 5.8.5, "condenser water pumps shall be modeled as fixed speed"
x8	Heated-only rooms	Modeled as intended.	Modeled per design.	Only supports heated and cooled. Heated-only spaces must be modeled with cooling systems.