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Subtask 1c Interim Report - Draft
DRAFT FINAL MEASURE LIST

Project

ASHRAE 1651-RP
Development of Maximum Technically Achievable Energy Targets for Commercial Buildings (Ultra Low Energy Use Building Set)

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Prepared for

Project Monitoring Subcommittee of ASHRAE MTG.ET Energy Targets Committee

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1 BACKGROUND

Task 1 is titled “Identify Best Available Technologies to be Modeled” and is described in part in the RFP as the following: “The contractor shall identify a comprehensive suite of technologies, and their associated performance metrics, to be included in the modeling.” This was divided into four subtasks:

Subtask 1a – Initial List of Energy Efficiency Measures

Subtask 1b – Review Sources to Expand List of EEMs

Subtask 1c – Compile Draft Final List and Report

Subtask 1d – Review Process and Update Report

This report describes the first three subtasks. An accompanying spreadsheet named “1651-1c-EEM-List.xlsx” is frequently referenced in the remainder of this report.

2 METHODOLOGY

2.1 Subtask 1a – Initial List of Energy Efficiency Measures

An initial list of measures was compiled based on personal experience of the principal investigator as well as measures found while reviewing the following sources:

- 1651-TRP Request for Proposal (ASHRAE 2011a)
- Energy Efficiency Manual (Wulfinghoff 1999)
- Advanced Energy Design Guides Scoping Committee for 50% Approach to Net Zero Energy Use in Commercial Buildings (ASHRAE 2006)
- EnergyPlus Input Output Reference for version 7.2 (DOE 2012a)
- Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector (Griffin 2007)
- EnergyPlus New Features List (DOE 2012b)
- Methodology for Modeling Building Energy Performance across the Commercial Sector (Griffith 2008).

Based on this review, a spreadsheet was created that contained 220 different energy efficiency measures, one measure per row. The columns of the spreadsheet are shown below along with a description:

- Category – A single word used to classify the measure into overall groups. The categories were daylighting, envelope, exterior load, HVAC, and internal load.
- Subcategory – Further detailed classification of each measure within each Category shown in Table 1 below.
- Measure – A short description of a building energy efficiency measure appropriate for new construction of commercial buildings. Most descriptions were just a few words long.
- Description – A description of the measure often a quote from the first source shown in the Source column.
- EnergyPlus – An indicator if the measure can be simulated using EnergyPlus. A question mark in this column indicates that it is not known if the measure can be simulated using EnergyPlus.
- Source – The reference to the source or sources in which the measure was identified along with specific identifiers such as a section number or page number from the reference.

The spreadsheet also includes a list of references in a second tab. This tab shows a bibliographic style reference for each as well as the abbreviation used on the main tab.

Table 1 Measure Subcategories

Category	*Subcategories*
Daylighting	Passive
	Active
Envelope	Fenestration
	Form
	Infiltration
	Opaque
Exterior Load	Lighting
HVAC	Control
	Cooling Efficiency
	Distribution Equipment Efficiency
	Heating Efficiency
	Distribution Pressure Drop
	Distribution Operation
	Service Water
	System
	Ventilation
Internal Load	Control
	Equipment
	Lighting
	Sensor

The RFP included the following list of energy efficiency measures as examples:

- Opaque envelope U-factors by climate zone for different envelope types
- Dynamic insulation performance ranges
- Fenestration U-factors and SHGCs by climate zone for different glazing types and percentages of wall area
- Dynamic fenestration performance ranges
- Infiltration rates
- Lighting power densities by building type
- Daylighting sources to be employed (e.g., light tube size, U-value, spacing)
- Daylighting control details (sensor locations, setpoints, control, etc.)
- Plug and process loads by building type
- Ventilation types by building type and climate zone (mechanical, natural, hybrid)
- HVAC system types, fuels and components by building type

- Cooling equipment COPs by equipment type and size
- Heating equipment efficiencies or COPs by equipment types and size
- Fan and pump efficiencies and static pressures by system type
- Economizer options (air side, water side) by building type and climate zone
- Ventilation system types by building type and climate zone (various types of mechanical options including heat recovery ventilation, dedicated outdoor air systems, etc., various types of natural ventilation options including air flow windows, etc.)
- Air distribution options by building type and climate zone, where not implicit in the HVAC system type (e.g., underfloor air distribution, displacement ventilation, overhead distribution)
- Control strategies by building type and climate zone
- Radiant heating and cooling options by building type and climate zone
- Thermal storage options by building type and climate zone
- Cogeneration options by building type and climate zone.

These were included in the list of measures as part of the initial list. Some of these such as "control strategies" were further divided into more specific efficiency measures in order to determine if EnergyPlus could simulate them or not.

While the review of the EnergyPlus Input Output Reference was not required for the first subtask, it appeared to be a good source of measures that could, by definition, be simulated using EnergyPlus. For the review of the EnergyPlus Input Output Reference, the IDF Editor feature to "Create objectList.txt" was used and a list of all input objects was generated based on the most recent Energy+.IDD file. This list of objects was used to ensure that all objects in EnergyPlus were reviewed as part of the subtask. Each object described in the Input Output Reference was assessed if it was the primary object used in modeling an energy efficiency measure. Often many objects are modified to implement a specific energy efficiency measure but it is usually one primary object that contains the key descriptors for the measure. The other objects that may be modified may serve as ways to identify schedules or connections with other objects or components. In addition, many objects in EnergyPlus serve a role in controlling the management, execution, output, or cost calculations of the simulation program such as the TimeStep object. These management objects were not considered as primary objects for any energy efficiency measure and were not reviewed. All non-management objects were reviewed in the Input Output Reference in order to determine what energy efficiency measures they would be used in. An example measure was identified for each. Several objects were found that did not seem to correspond to any energy efficiency measure. Some non-management objects were also identified as being used to simulate measures not included in the scope of the project such as photovoltaics.

In addition to a list of measures, a list of references to books, periodicals, reports and papers was collected during the process. Some of these sources were specifically cited in the original request for proposal or in the proposal but many were found during the search of the materials described or were references known to the principal investigator.

The spreadsheet was distributed by email for public review to the following:

- Core EnergyPlus development team (about 40 people)
- EnergyPlus-developers mailing list (about 100 outside software developers)
- EnergyPlus-support mailing list (about 3000 users of EnergyPlus).

The email sent stated:

> "As part of ASHRAE research project 1651-RP, we are trying to assemble of list of energy efficiency measures that can be considered for new buildings covered by 90.1. The project is titled: "Development of Maximum Technically Achievable Energy Targets for Commercial Buildings (Ultra Low Energy Use Building Set)". Later we will be looking for the combination of measures that will result in the lowest possible energy consumption for each building type using EnergyPlus. The measures do not include renewables and are not restricted by first costs.
>
> Your help is requested to:
>
> a) Add any measures that I have missed on the "EEMs" tab of the spreadsheet.
>
> b) Add any web or literature sources that I may have missed on the "References" tab especially those that contain lists of energy efficiency measures.
>
> If you have suggestions, it would be most helpful if you replied only to me with a revised version of the spreadsheet attached containing additional rows at the bottom of each tab with your input.
>
> After we finish compiling the list, we will be choosing a subset of measures to simulate using EnergyPlus. This is the first of several reviews of the list of measures.
>
> Thanks, your help is appreciated."

Some feedback was received including suggested measures. Those suggested measures were reviewed and, when appropriate, incorporated into the Subtask 1b spreadsheet.

2.2 Subtask 1b – Review Sources to Expand List of EEMs

For subtask 1b, the list of sources that were reviewed were:

- ASHRAE Advanced Energy Design Guides (AEDG2004, AEDG2006, AEDG2008a, AEDG2008b, AEDG2009a, AEDG2009b, AEDG2011a, AEDG2011b, AEDG2011c, AEDG2012)
- Standard 90.1 (ASHRAE 2010)
- Standard 189.1 (ASHRAE 2011b)
- ASHRAE Transactions
- ASHRAE Journal

- HVAC&R Research
- High Performance Buildings magazine
- DOE High Performance database (DOE 2012c)
- Environmental Design and Construction magazine
- Building Design and Construction magazine.

The result of this review was the expanding of the list of energy efficiency measures to 320 different measures. In addition, each measure was assessed in greater detail. The added details were to reflect the following requirements from the request for proposal:

1. Measures shall be included only if they currently are, or by 2030 can reasonably be expected to be, offered by at least two manufacturers.
2. Technologies shall include gas and electric options for end-uses where both technologies are available.

The columns added to the spreadsheet to address these issues are:

- Gas Technology
- Electric Technology
- Current Technology
- Two Manufacturers Now
- Two Manufacturers by 2030.

For each of these five columns, a yes or no appears for each measure that can be modeled in EnergyPlus. Measures that could not be modeled in EnergyPlus were not assessed since they ultimately will not be modeled in later project tasks. Almost all the measures were identified as current technology and having at least two manufacturers now. For measures that are site built, they are considered to be manufactured at the site and are indicated with a yes in the manufacturing columns.

Additional columns were also added or modified related to how the measure would be simulated:

- EnergyPlus – This column was modified to contain either direct, indirect, or no. Direct indicates that EnergyPlus has inputs that are intended to model the energy efficiency measure. Indirect indicates that to model the measure in EnergyPlus would require using its capabilities in ways that may not have been the original intent of the model but is thermodynamically equivalent or nearly equivalent.
- Autosizable – Indicates that for an HVAC component it can be automatically sized which is important when determining how difficult it would be to model the measure.
- Objects to Modify – Shows a list of EnergyPlus objects which would be the primary objects to modify or include in order to model the measure.

- Difficulty – This column can be either simple or complex and determines the level of difficulty to model the measure in EnergyPlus. Later tasks will model 15 simple and 15 complex measures in EnergyPlus.

The ASHRAE Advanced Energy Design Guides (AEDG), at the time of the review, include the following:

- Advanced Energy Design Guide for Small Office Buildings. Achieving 30% Energy Savings Toward a Net Zero Energy Building (AEDG2004)

- Advanced Energy Design Guide for Small Retail Buildings. Achieving 30% Energy Savings Toward a Net Zero Energy Building (AEDG2006)

- Advanced Energy Design Guide for Small Warehouses and Self-Storage Buildings. Achieving 30% Energy Savings Toward a Net Zero Energy Building (AEDG2008a)

- Advanced Energy Design Guide for K-12 School Buildings. Achieving 30% Energy Savings Toward a Net Zero Energy Building (AEDG2008b)

- Advanced Energy Design Guide for Small Hospitals and Healthcare Facilities. Achieving 30% Energy Savings Toward a Net Zero Energy Building (AEDG2009a)

- Advanced Energy Design Guide for Highway Lodging. Achieving 30% Energy Savings Toward a Net Zero Energy Building (AEDG2009b)

- Advanced Energy Design Guide for Small to Medium Office Buildings. Achieving 50% Energy Savings Toward a Net Zero Energy Building (AEDG2011a)

- Advanced Energy Design Guide for K-12 School Buildings. Achieving 50% Energy Savings Toward a Net Zero Energy Building (AEDG2011b)

- Advanced Energy Design Guide for Medium to Big Box Retail Buildings. Achieving 50% Energy Savings Toward a Net Zero Energy Building (AEDG2011c)

- Advanced Energy Design Guide for Large Hospitals. Achieving 50% Energy Savings Toward a Net Zero Energy Building. Atlanta, Georgia (AEDG2012).

Each AEDG includes specific recommendations on achieving the percent savings by climate zone such as insulation, lighting power density, and equipment efficiency. In addition, the AEDGs each provide a chapter on how-to tips called “How to Implement Recommendations”. These sections in each AEDG contain more than one hundred tips, many of which are specific energy efficiency measures. Since the later AEDGs have been built upon the work of previously published AEDGs, the how-to tips are often repeated from one publication to the next. The titles of each how-to tip were collected and each how-to tip was reviewed only once even if it appeared in more than one AEDG. It is expected that some editing of a how-to tip with a specific titled occurred between various AEDGs but that it would still represent the same energy efficiency measure. Over 450 different unique titles for tips were found across the ten AEDG books. At times, the titles appear to have changed but the content of the how-to tip did not. The review of the AEDG provided a large number of new measures to the list.

The next source to be reviewed was the High Performance Building Database (DOE 2012c) that the U.S. Department of Energy provides at:

http://buildingdata.energy.gov/hpbd

At the time of the review, it contained 144 different examples of high performance buildings. The descriptions of the buildings in the database include many different facets but the section titled “Energy” was the focus of this review. This section described the energy related features of the building and usually mentioned a series of energy efficiency measures implemented for the building. The result of this review was eleven additional measures that had not been uncovered previously.

Several magazines and journals were reviewed as part of this subtask. All were reviewed for publications over a one year period, 2012. Table 2 indicates the publication and results of the review. The number of measures discussed was far more than shown but most had already been previously identified.

Table 2 – Magazine and Journal Review

Publication	*Issues*	*Articles*	*New Measures Found*
High Performance Building Magazine	4	19	2
HVAC&R Research	5	1	1
EDC Magazine	12	many	0
ASHRAE Journal 12	12	30	2
Building Design and Construction	12	many	0
ASHRAE Transactions	2	39	6

For HVAC&R Research only abstracts were reviewed. For ASHRAE Journal, the Technology Award related articles were reviewed along with the Emerging Technology articles. For ASHRAE Transactions, almost 200 titles were first assessed and those that looked promising, 39, were examined in more detail. The most successful of these reviews was the ASHRAE Transactions.

An extensive list of other sources were identified as part of this subtask but were not reviewed since the previously discussed sources had been so successful in identifying so many measures.

A detailed examination of the figure of merit for each measure, such as COP, was delayed due to the large number of measures found.

2.3 Subtask 1c – Compile Draft Final List and Report

Members of the EnergyPlus development team were contacted to help classify thirty-six measures to determine if EnergyPlus could model them. Different approaches were suggested for many of these measures since they were all classified as being able to be modeled or would be likely to be able to be modeled in the upcoming version of EnergyPlus.

Of the 320 energy efficiency measures in list, EnergyPlus should be able to model all but twelve. Five of these twelve may be implemented in the upcoming version of EnergyPlus, version 8.0. From the 320 measures, 235 are classified as "direct" meaning that EnergyPlus has explicit support for the measure

without any workarounds. The remaining 73 “indirect” measures can be modeled using various workarounds.

Of the 320 energy efficiency measures in the list, 209 are classified as simple to model, 88 are classified as complex, 11 are classified as simple or complex depending on the modeling method chosen, and 12 were not categorized because they could not be modeled in EnergyPlus. This assessment may change as the level of understanding how to implement each measure increases as the list gets narrowed to only those that will be modeled in the project.

Further analysis of the list of measures was done as part of the “Recommended EnergyPlus Enhancements” discussed in the next section.

3 RECOMMENDED ENERGYPLUS ENHANCEMENTS

While EnergyPlus can model a very large fraction of the list of measures (308 of 320) this does not mean that the models within EnergyPlus could not be improved. If a particular measure was previously categorized as being modeled indirectly in EnergyPlus, complex to model, or not autosizable, then it was classified as something that could be enhanced in EnergyPlus. It was also classified this way if it corresponded to an item on the existing EnergyPlus Enhancement List as described below.

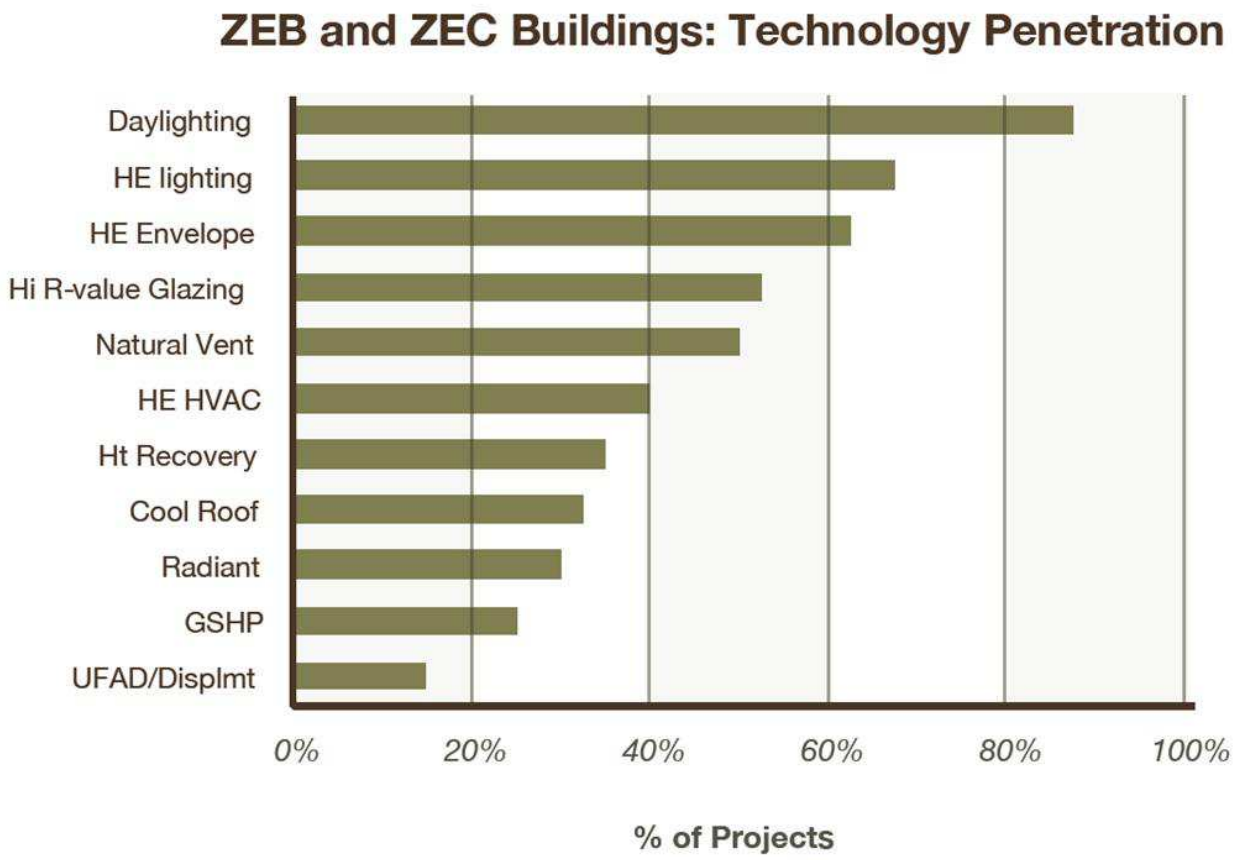
The existing EnergyPlus Enhancement List (DOE 2012d) that is used by the core EnergyPlus development team was reviewed as part of the process to create recommendations for possible enhancements. The list contained 366 items at the time of review (near the end of 2012). This list is used to prioritize enhancement ideas for future versions of EnergyPlus. The list is primarily the result of suggestions from the members of the core development team. The list is categorized into over 40 different groups such as “Ventilation”, “Geometry”, etc.

EnergyPlus Enhancement List items in the following categories that were unrelated to energy efficiency were not examined: documentation, execution time, utilities, input and output, testing, training and validation. This removed 85 items from the list. Upon review, 56 additional items were removed related to documentation, utilities, restructuring or refactoring of source code, reporting, new solver methodologies, and renewable system modeling. Each remaining EnergyPlus Enhancement List item was reviewed and 100 items were identified as related directly to an energy efficiency measure. These were indicated in the energy efficiency measure list spreadsheet in the “Could Enhance EnergyPlus” column as “Yes-enhancement list”.

Based on this review, of the 320 energy efficiency measures in list, 153 would warrant improvements in EnergyPlus. Clearly, this is too many possible improvements to recommend. Prioritizing the recommendations was necessary.

During the literature search for energy efficiency measures in various case studies, some measures occurred frequently. These are shown as Yes in the “Common Measures” column in the spreadsheet and were based on a subjective evaluation since no counting of measure frequency was performed. Of the 320 energy efficiency measures, 65 were classified as “Common Measures.”

The New Building Institute report “Getting to Zero 2012 Status Update: A First Look at the Costs and Features of Zero Energy Commercial Buildings” (NBI 2012) included a list of 11 technologies that were frequently found in the small set of zero energy commercial buildings assessed as part of that report. The graph from that assessment is shown below:



Each of these technologies was mapped to energy efficiency measures in the list. Of the 320 energy efficiency measures, 49 were classified Yes in a spreadsheet column labeled “Getting to Zero Measures.”

If a measure was either considered a “Common Measure” or a “Getting to Zero Measure” and was one of the 153 measures that would warrant improvements in EnergyPlus, it was considered a “Recommended Enhancement”. Of the 320 energy efficiency measures, 37 were classified as “Recommended Enhancements.”

Finally, the list of measures was reviewed one last time applying engineering judgment to remove some and add others. Some of the “Recommended Enhancements” were eliminated because the type of enhancement recommended by the EnergyPlus development team was not directly pertinent to the models expected to be developed during the project. In addition, a few measures were added because they were likely to be selected as possible measures even though they were not identified as common. For some measures, activity was already underway to add the features to EnergyPlus so they were removed. The results are shown in the “Final Enhancement Recommendation” column and include 32 of the 320 energy efficiency measures being associated with enhancements, as shown in the Table 3 in alphabetical order:

Table 3 Final Recommended EnergyPlus Enhancements

Energy Efficiency Measure	*EnergyPlus Enhancement*
Building nighttime precooling using ventilation	Add Autosizing
Cross ventilation with operable windows	Simplify
Demand controlled ventilation/CO2 controls	Simplify/EL
Direct evaporative cooling	Add Autosizing
Displacement ventilation	Simplify/EL
Geothermal pond-based heat pumps	Simplify/EL
Greenhouse for heating	Simplify
Ground source heat pump	Simplify/EL
Ground source heat pump with cooling tower	Simplify/EL
High performance cooling towers	EL
Highly insulated ducts	Simplify
Hybrid/mixed mode ventilation	Simplify/EL
Internal light shelves	EL
Maisotsenko cycle-Coolerado evaporative cooling	Add direct model/EL
Movable window overhangs and fins	Add direct model/EL
Natural ventilation	Simplify/EL
Night sky cooling system	Add direct model
Occupant sensors	Add direct model
Occupant sensors for task lighting	Add direct model
Optimal choice of skylight construction	EL
Optimal choice of vertical fenestration construction	EL
Radiant cooling	EL
Radiant heating	EL
Radiant heating and cooling and DOAS	EL
Radiant heating and cooling with displacement ventilation	Simplify
Right size equipment	Add Autosizing
Seasonal thermal storage	Add direct model
Sensible and latent exhaust air heat recovery	Add Autosizing
Sensible exhaust air heat recovery	Add Autosizing
Sun tracking tubular daylighting devices	Add direct model
Tubular daylighting devices	EL
Vegetative roof	EL

EL indicates an item in the EnergyPlus development team's enhancement list.

The specific enhancements to EnergyPlus that are recommended are shown below.

- Add direct models in EnergyPlus for Maisotsenko Cycle-Coolerado evaporative cooling, movable window overhangs and fins, night sky cooling system, occupant sensors, seasonal thermal storage, and sun tracking tubular daylighting devices.

- Add autosizing capabilities to EnergyPlus for building nighttime precooling using ventilation, direct evaporative cooling, exhaust air heat recovery, radiant systems, other HVAC components that are not currently autosizable.

- Simplify the input requirements for demand controlled ventilation/CO2 controls, displacement ventilation, ground and pond based geothermal heat pumps, greenhouse for heating, insulated ducts, natural and hybrid/mixed mode ventilation including cross ventilation with operable windows.

- For demand controlled ventilation, add enhanced controls based on adaptive temperatures, include outdoor airflow rate from zone equipment, and add a multi-zone set point manager and critical zone control.

- Improve the existing displacement ventilation model to better capture air stratification.

- For geothermal pond-based heat pumps, add ice-on-pipe sub-model to account for ice build-up around glycol loops, add ice-on-pond sub-model to account for ice build-up on the water surface, add thermal stratification model to account for temperature gradients in surface water heat exchangers, and allow for flow through the pond, such as a river or spring, which keeps the lower part of the pond flowing, even though the top of the pond might freeze.

- For ground source heat pump, develop datasets for vertical ground heat exchangers, add auxiliary tool to generate input values for ground heat exchanger, eliminate incompatibility between borehole resistance and g-functions to provide a more stable solution for certain configurations.

- For high performance cooling towers, enhance the tower models to include a reset ratio.

- For hybrid/mixed mode ventilation, support use of zone equipment during hybrid operation, add zone-by-zone control, and add support for more coil types.

- For internal light shelves, allow beam solar to bypass the light shelf when appropriate rather than assuming all beam is absorbed by the shelf.

- For movable window overhangs and fins, add capability for surface geometry to change during the simulation period.

- For optimal choice of vertical or skylight fenestration construction, allow more than four glazing layers, support other window materials such as phase change materials or aerogels, and upgrade the models to match the Window 6 program.

- For radiant heating and cooling systems, add simple chilled ceiling model, add humidity and surface temperature control schemes, improve the modeling of condensation scenarios, and add true thermostatic controls.

- For tubular daylighting devices, enhance the model to be able to have a hemispherical dome, to allow better thermal modeling, and to define grids of devices instead of one at a time.

- For vegetative roof, enhance the model reflecting the best validated models including evapotranspiration.

While these are also not shown in priority order, those enhancements that are related to daylighting, heat pumps, energy recovery, radiant heating and cooling, and natural ventilation are probably the most important since they are very likely to be measures that are selected in later stages of the project.

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