

providing insights for today's hvac system designer

Engineers Newsletter

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LEED® v4

The Leadership in Energy and Environmental Design (LEED®) rating system is one of the preeminent green building rating systems in the U.S. and globally. With effort from numerous volunteers and United States Green Building Council (USGBC) committees, LEED v4 was approved in late June 2013 and launched at Greenbuild in November 2013. This newsletter discusses the changes and the challenges of meeting the requirements in LEED v4.

Credit point structure

The LEED Steering Committee approved a set of new impact categories and a new weighting tool for LEED v4 to address not only environmental goals, but also social and economic goals.^[1] LEED v4 refines the category and point structure based on relevance to the built environment (Table 1).

This EN focuses on New Construction (NC) credits and points specific to HVAC. For more specific guidance, readers should refer to the LEED Reference Guide.^[2]

Integrative Process. The intent of this new category is to support high performance, cost-effective project outcomes through an early analysis of the green design and construction strategies. For project teams working in healthcare, integrative project planning and design is a prerequisite.

Table 1. Point distribution for New Construction

Credit categories	LEED 2009	LEED v4	Point gain/loss
Integrative Process ¹		1	+1
Location and Transportation ^{1,2}		16	-
Sustainable Sites ²	26	10	-
Water Efficiency	10	11	+1
Energy and Atmosphere	35	33	- 2
Materials and Resources	14	13	- 1
Indoor Environmental Quality	15	16	+1
Innovation and Design Process ³	6	6	-
Regional Priority ³	4	4	-

¹New category in LEED v4

²Since the combined points in **Location and Transportation** and **Sustainable Sites** categories in LEED v4 are equal to the points in the **Sustainable Site** category in LEED 2009, we indicate "no change" in the points gain/loss column.

³Bonus points available toward maximum of 100 points total

To achieve credit, project teams must perform a "simple box" energy model for energy-related systems and a preliminary water budget for water-related systems. This allows exploration of ways to reduce both water and energy use while also accomplishing related sustainability goals. Project teams must document how their early analysis influenced their design decisions.

Location and Transportation (LT). This new category pulls several credits from the 2009 Sustainable Sites category. For the Green Vehicle credit, other than the name, the most notable change is that it's worth only one point, compared to three

points in the previous version. Providing preferred parking spaces alone is no longer enough to earn this credit, you must provide preferred or discounted parking for green vehicles, plus one of two options for refueling stations.

LEED v4 introduces a simplified path for earning LT points. If the project is located in an area that has already been certified through the *LEED for Neighborhood Development* (ND) rating system, the project can earn points based on that certification level. This makes sense because the planning for transportation and access to surrounding services has already been completed through LEED ND certification.

Table 2. Location and Transportation Credits

LEED 2009	NC points	LEED v4	NC points
Site Selection	1	Sensitive Land Protection	1
Brownfield Redevelopment	1	High-Priority Site	1-2
Development Density and Community Connectivity	5	Surrounding Density and Diverse Uses	1-5
Public Transportation Access	6	Access to Quality Transit	1-5
Bicycle Storage & Changing Rooms	1	Bicycle Facilities	1
Parking Capacity	2	Reduced Parking Footprint	1
Low-Emitting, Fuel-Efficient Vehicles	3	Green Vehicles	1

Table 3. Sustainable Sites Credits

LEED 2009	NC points	LEED v4	NC points
		Site Assessment	1
Protect or Restore Habitat	1	Protect or Restore Habitat	1-2
Maximize Open Space	1	Open Space	1
Stormwater – Quantity Control	1	Rainwater Management	1-3
Stormwater – Quality Control	1		
Heat Island Effect – Nonroof	1	Heat Island Reduction	2
Heat Island Effect – Roof	1		
Light Pollution Reduction	1	Light Pollution Reduction	1

Table 4. Water Efficiency Credits

LEED 2009	NC points	LEED v4	NC points
Water Efficient Landscaping	2-4	Outdoor Water Use Reduction	1-2
Innovative Wastewater Technologies	2		
Water Use Reduction	2-4	Indoor Water Use Reduction	1-6
		Cooling Tower Water Use	1-2
		Water Metering	1

Projects not located on a LEED ND site can earn points by meeting the requirements of the credits listed in Table 2.

Sustainable Sites (SS). Referenced standards for Sustainable Site prerequisites have been updated to newer versions. For example, construction activity pollution prevention now refers to the 2012 version of the EPA's Construction General Permit.

The new Site Assessment credit awards one point for conducting an early survey of the site conditions (e.g., topography, vegetation, soils, human health, etc.).

To minimize Heat Island Effect, LEED v4 combines the calculation methods for nonroof and roof measures, along with vegetated roofs, into a single credit. For non-roof measures, solar reflectance values and a 3-year aged solar reflectance value are used instead of solar reflectance index.

The remaining credits shown in Table 3 for the SS category have only minor changes.

There are also specific credits available for schools, core and shell and healthcare.

Water Efficiency (WE). LEED v4 expands from one prerequisite to three prerequisites including Indoor Water Use Reduction, Outdoor Water Use Reduction, and Building-Level Water Metering. The Water Efficiency credits are listed in Table 4. The new credit Indoor Water Use Reduction not only requires all newly installed fixtures and fittings to be WaterSense® labeled (or a local equivalent for projects outside the U.S.) but also requires appliance and process water use reduction. Specific requirements for processes include no once-through cooling with potable water for heat rejection equipment, required makeup water metering, conductivity controllers, overflow alarms, and efficient drift eliminators for cooling towers.

The objective of the Cooling Tower Water Use credit is to conserve water lost through blowdown. Blowdown is the process of replacing the cooling tower water to avoid high dissolved solids concentration levels caused by evaporation. To achieve points under this credit, project teams must conserve cooling tower makeup water by maximizing water cycles and keeping the cooling tower parameters below maximum concentrations levels.

Water Metering, a new credit, awards a point for advanced water-consumption tracking. It can be achieved by installing permanent water meters for two or more subsystems. For example, if a project team monitors 80 percent of both irrigation water and domestic hot water, they would earn one point.

Energy and Atmosphere (EA). Table 5 lists EA prerequisites. LEED v4 has moved to ASHRAE Guidelines 0 and 1.1 as the basis for commissioning guidance for the Fundamental Commissioning and Verification prerequisite. And, for the first time, the building envelope (or enclosure) is covered by this prerequisite. Although the prerequisite does not require envelope commissioning, the commissioning agent needs to make sure it complies with the Owner's Project Requirements and the Basis of Design.

Table 5. Energy and Atmosphere Prerequisites

LEED 2009		LEED v4	
Fundamental Commissioning	X	Fundamental Commissioning and Verification	X
Minimum Energy Performance	X	Minimum Energy Performance	X
		Building-Level Energy Metering	X
Fundamental Refrigerant Management	X	Fundamental Refrigerant Management	X

Table 6. Energy and Atmosphere Credits

LEED 2009	NC points	LEED v4	NC points
Enhanced Commissioning	2	Enhanced Commissioning	2-6
Measurement and Verification	3		
Optimize Energy Performance	1-19	Optimize Energy Performance	1-18
		Advanced Energy Metering	1
		Demand Response	1-2
On-site Renewable Energy	1-7	Renewable Energy Production	1-3
Enhanced Refrigerant Management	2	Enhanced Refrigerant Management	1
Green Power	2	Green Power and Carbon Offsets	1-2

The second prerequisite is Minimum Energy Performance. The basis for the minimum requirement threshold has changed— from the 2007 version of ASHRAE Standard 90.1 to the 2010 version. For all the options of this prerequisite, 90.1-2010 mandatory requirements must be met. In the mechanical section, this includes full- and part-load equipment efficiency requirements, controls, insulation, and others. Figure 1 illustrates the three compliance options. From a high level, the three options are:

- Whole Building Energy Simulation using Appendix G from 90.1 – and being 5 percent more stringent for new construction, 3 percent better for

major renovation, or 2 percent better for core and shell projects

- Using the 50 Percent Advanced Energy Design Guides (AEDG)
- Or using the Advanced Buildings™ Core Performance® Guide from the New Buildings Institute.

For a review of the changes to 90.1-2010 compared to the 2007 version, please refer to the *Trane Engineers Newsletter*, volume 39-3, "ASHRAE 90.1-2010." [3]

There is a new prerequisite called Building Level Energy Metering. Either building or aggregated sub-metering is required for all the energy uses in the building. Depending on the energy sources, this may be a

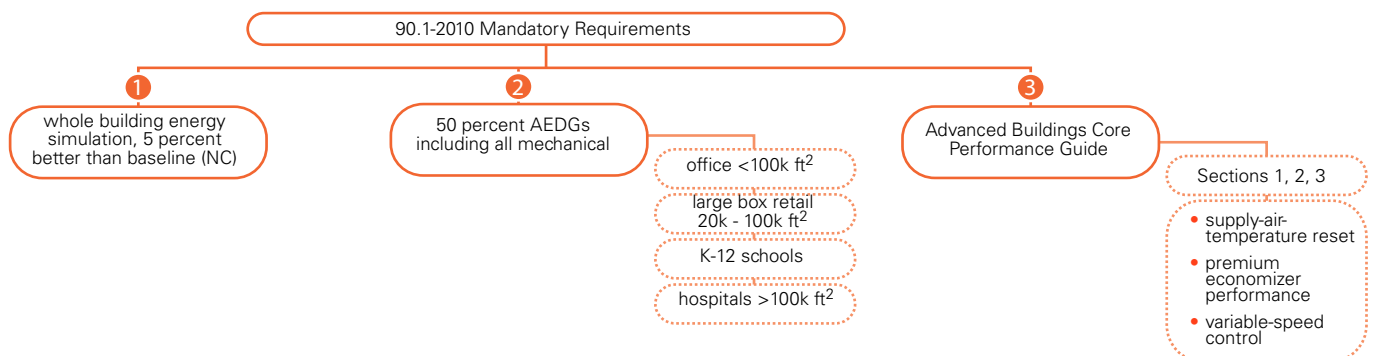
significant increase in metering. For electricity, consumption (in kWh) and demand (in kW) data must be tracked. Also, energy data must be tracked and shared with USGBC for all energy uses, at least monthly, for five years.

The last prerequisite, *Fundamental Refrigerant Management*, was not changed. It still does not allow use of CFCs (such as R-11 or R-12). Primarily this was kept because LEED is being adopted in developing countries where CFCs may still be used on non-LEED projects.

Energy and Atmosphere (Table 6) remains the largest credit category for LEED points, comprising up to 33 percent of potential credit points. There were a few reallocations within the EA section.

Enhanced Commissioning. The Measurement and Verification credit of LEED 2009 migrated into this category in LEED v4. Enhanced commissioning must be done by a third party with experience on at least two similar projects. In addition, the commissioning agent's involvement spans from early design phase through at least ten months of occupancy. The first path, worth three points, is to perform enhanced commissioning. The second path, a four point alternative, is to perform both enhanced commissioning AND assessing energy and water performance. In addition, two points are available for envelope commissioning. Since envelope commissioning is not generally performed today, when performed in accordance with the requirements, points are awarded.

Figure 1. Three options to comply with EA prerequisite: Minimum Energy Performance



Optimize Energy Performance. To earn points through option 1, the proposed project must be modeled and compared to a baseline building. Energy cost is still the metric, but LEED v4 now uses Appendix G of ASHRAE 90.1-2010 instead of 90.1-2007. By exceeding the level of savings required by the prerequisite, points can be earned. The maximum number of points varies by building type. Table 7 shows how many points are achieved at different levels of energy cost savings in different construction types. A 1 percent improvement over the prerequisite in any of the construction categories begins earning points. Note that a 1 percent of improvement for healthcare receives three points – compared to one point in all other building categories.

For buildings covered by a 50 percent AEDG, one point can be achieved in option 2 by following the recommendations prescriptively in each of the following categories:

- building envelope (opaque),
- building envelope (glazing),
- interior lighting,
- exterior lighting, and
- plug loads.

A sixth possible point for the lighting on the sales floor can be earned for medium and big box retail buildings.

Advanced Energy Metering. This new credit requires sub-metering all “individual energy end uses” that are at least 10 percent of the total building annual energy consumption. These sub-meters must be permanently installed with storage and remote access capability to report energy use—from hourly to annual. Also, electric meters must have these capabilities for both consumption and demand.

Demand Response. This new credit can achieve either one or two points. The goal is to have an automated system that can either shed or shift load. To earn this credit, the project must have an automated and commissioned system capable of a 10 percent demand reduction. The difference is that two points are available if there is a contract for demand response, while only one point is available if there is no such program in place.

Renewable Energy Production. This credit is reduced to three points in LEED v4 compared to the seven possible points in LEED 2009. The three points are earned for

using various levels of renewable energy. Solar gardens or community renewable energy systems are allowed if the project owns the system or has a lease agreement for at least 10 years, and the system is located in the same utility service area as the facility claiming the use.

Enhanced Refrigerant Management. The number of points changed from two in 2009 to one in v4. An additional change is that if all equipment on a project uses refrigerants with zero ozone depletion potential (ODP) and less than 50 global warming potential (GWP), the credit is given. If other refrigerants are used, a calculation must be performed, but there are no changes from the 2009 equation. Retail commercial refrigeration allows present freezer case refrigerants to be used as long as the refrigerant charge is no more than 1.75 lb of refrigerant per 1000 Btu/h, and the store-wide annual refrigerant emissions are less than 15 percent.

Green Power and Carbon Offsets. Up to two points are available for purchase of green power, renewable energy certifications or carbon offsets – but the requirements of v4 are more stringent. The levels of purchase are 50 percent for one point and 100 percent for two points. In addition, the qualified resources must have come online since January 1, 2005 and a contract for at least five years must be in force.

Materials and Resources (MR). The Storage and Collection of Recyclables prerequisite now includes specific safety measures for at least two types of the following products: batteries, mercury-containing lamps, and electronic waste. The Construction and Demolition Waste Management prerequisite was a credit in 2009. It was elevated to a prerequisite in v4. To comply, waste diversion targets need to be defined, and a final report must be submitted. The last prerequisite on Persistent, Bioaccumulative and Toxic Pollutants applies to healthcare projects, and has not been changed in v4.

There has been a lot of shuffling and re-naming of credits in this category. The new Building Product Disclosure and Optimization – Environmental Product Declarations (EPDs) credit is of particular interest. There are two points available in the EPD credit. To receive the first point, the project must use at least 20 different permanently-installed products, sourced from at least five different manufacturers that meet the disclosure

Table 7. Energy cost savings and Optimize Energy Performance Credits

Energy cost savings by construction type			Optimize Energy Performance points earned by building type		
New Construction	Major Renovation	Core and Shell	All others	Healthcare	Schools
5%	3%	2%		Prerequisite	
6%	4%	3%	1	3	1
8%	6%	5%	2	4	2
10%	8%	7%	3	5	3
12%	10%	9%	4	6	4
14%	12%	11%	5	7	5
16%	14%	13%	6	8	6
18%	16%	15%	7	9	7
20%	18%	17%	8	10	8
22%	20%	19%	9	11	9
24%	22%	21%	10	12	10
26%	24%	23%	11	13	11
29%	27%	26%	12	14	12
32%	30%	29%	13	15	13
35%	33%	32%	14	16	14
38%	36%	35%	15	17	15
42%	40%	39%	16	18	16
46%	44%	43%	17	19	16
50%	48%	47%	18	20	16

Table 8. Indoor Environmental Quality Credits

LEED 2009	NC points	LEED v4	NC points
Outdoor Air Delivery Monitoring	1		
Increased Ventilation	1	Enhanced IAQ Strategies	1-2
Indoor Source Control	1		
Low-Emitting Materials	1-4	Low-Emitting Materials	1-3
Construction IAQ Management Plan – During Construction	1	Construction IAQ Management Plan	1
Construction IAQ Management Plan – Before Occupancy	1	IAQ Assessment	1-2
Controllability of Systems – Lighting	1	Interior Lighting	1-2
Controllability of Systems – Comfort	1		
Thermal Comfort – Design	1	Thermal Comfort	1
Thermal Comfort – Verification	1		
Daylight and Views – Daylight	1	Daylight	1-3
Daylight and Views – Views	1	Quality Views	1
Acoustic Performance (1-2 points for Schools and Healthcare only)		Acoustic Performance (all buildings, except Retail)	1

criteria. Declarations are weighted differently. Third-party product specific declarations are worth more than self-declarations. To earn the second point under this credit, at least 50 percent of the products, based on cost, need to meet criteria demonstrating their environmental impact reduction in at least three environmental categories. Products that are extracted, manufactured, and purchased within 100 miles of the project site are valued at twice the product cost.

The LEED Reference Guide provides a list of useful resources to find EPD programs around the world. One of those programs is operated by the Institute for Construction and Environment in Germany. There are over 500 EPD products listed on that website, including Trane’s EarthWise™ CenTraVac™ centrifugal chiller, the first EPD-certified air conditioning product in the world.

Indoor Environmental Quality (EQ). The EQ section has the same prerequisites, Minimum IAQ Performance, which is basically complying with ASHRAE Standard 62.1, and dealing with tobacco smoke. In addition, *LEED for Schools* has one more prerequisite focused on acoustics. The first major change to the Minimum IAQ Performance prerequisite is the updated reference to the 2010 version of ASHRAE Standard 62.1.^[4] As in the past, a project must meet all requirements listed in

Sections 4 through 7 of the standard, which means complying with more than just the ventilation rates. LEED allows use of either the Ventilation Rate Procedure or the new Natural Ventilation Procedure. But use of the IAQ Procedure is not allowed.

The second major change to this prerequisite is that it now requires monitoring. (In LEED 2009, Outdoor Air Delivery Monitoring was a credit.) For a mechanical ventilation system with variable airflow, you must directly measure outdoor airflow, for example, with a Trane Traq™ damper. Due to large number of changes between 2007 and 2010 versions of 62.1, we summarize the most significant changes in the inset below.

Table 8 compares EQ credits between LEED 2009 and v4.

ASHRAE Standard 62.1-2010 significant changes over 62.1-2007.	
section	change
6.2.1	Added MERV 11 requirement for PM2.5 non-attainment areas, and more stringent requirements for ozone air cleaning
6.2.7.1	Prescriptive requirements for DCV and other reset strategies
6.4	Prescriptive requirements for natural ventilation (location and size of openings, controls), requires "mixed-mode" systems in most applications
6.1, 6.5	Clarified that exhaust airflow requirements are required regardless of which procedure is being used
5.5.1	Simplified intake/exhaust separation requirements (by air class)
6.2	Clarified Ventilation Rate Procedure calculations

Enhanced IAQ Strategies. Outdoor Air Delivery Monitoring, Increased Ventilation, and Indoor Source Control have been combined into a single credit, worth either one or two points. There are two options for earning points in this credit. Using option 1, you can earn one point by meeting all the requirements that were essentially part of the old Indoor Source Control credit. In addition, using option 2, you can earn one more point by implementing any one of several IAQ strategies listed.

For example, one of the choices is the old Increased Ventilation credit. If you design the system so that the breathing zone ventilation rates are 30 percent higher than Standard 62.1, you can earn this additional point. Or, you can choose to monitor CO₂ in each densely-occupied space. In total, there are four strategies to choose from under option 2. So if you comply with any one of them, you earn this additional point.

IAQ Assessment. This credit, which has been renamed, still has 2 options for earning points. Option 1, worth one point, involves flushing-out the building with outdoor air prior to occupancy. The flush-out process is essentially unchanged, but v4 clarifies the indoor temperature and humidity limits that must be maintained during this process. Also, movable furnishings must be in place before the flush-out begins.

Alternatively, you can use option 2, which for v4 is now worth two points. This approach involves sampling and testing the air prior to occupancy. In addition to being worth an extra point, testing for additional contaminants is required.

Thermal Comfort. In 2009, you could earn one point for Thermal Comfort Design, one point for Thermal Comfort Verification, and one point for Controllability of Thermal Comfort. In v4, these three have been consolidated into a single credit, worth one point. The project must meet ASHRAE Standard 55-2010. But, the requirements for Thermal Comfort Verification have been removed in v4.

Acoustic Performance. This EQ credit is new for many of the building types. In LEED 2009, both *LEED for Schools* and *LEED for Healthcare* included a credit for acoustic performance. For v4, this credit now applies to *all* building types, except retail.

Starting with schools, LEED 2009 had a prerequisite and a credit worth one point. The same is true for v4, but the requirements are now more stringent. To meet the prerequisite, the background sound level from the HVAC system in classrooms and core learning spaces must be 40 dBA or less; compared to 45 in 2009. And to earn the one credit point, the background sound level must be even quieter, 35 dBA or less. The reference to ANSI Standard S12.60 was also updated to the 2010 version.

A more significant change is a requirement to consider exterior noise sources. If the school is located within a half mile of a significant noise source, like a highway, industrial facility, rail line, or flight path, then measurements at the site must be taken. If the measured sound level exceeds a defined threshold, strategies that reduce noise transmission from outside must be implemented.

For healthcare buildings, the requirements of this acoustic credit are essentially unchanged and can earn up to two points.

To earn one point for the acoustic credit for other building types, all the occupied spaces in buildings must meet the corresponding background sound levels listed in the *ASHRAE Handbook*, as well as the reverberation times and STCs published in the LEED rating system.

And finally, if the project includes sound reinforcement or masking systems, this credit includes requirements for how those systems are to be designed.

Innovation (IN). Innovation points are also restructured. Three of the following strategies can be used to earn up to a maximum of five points in the innovation credit category.

strategies	max. points
Innovation	3
Pilot credit	3
Exemplary Performance	2

Available pilot credits can be found in the USGBC pilot credit library. An exemplary performance point is typically earned for achieving double the credit requirements or the next incremental percentage threshold of an existing credit.

Regional Priority (RP). The rules for achieving these credits is the same as LEED 2009. If the project earns a Regional Priority credit, it will also earn the associated bonus point. LEED v4 expanded regional priority credits to international projects.

Final Thoughts

As the LEED rating system progresses by referencing the latest available ASHRAE standards such as 90.1, 62.1, and 55, it is imperative for HVAC practitioners to stay abreast of the relevant standards. In addition to keeping up with changes, here are some tips when working on LEED v4 projects.

- Remember to pick the low hanging fruit first. Although the bonus points are introduced toward the end of the LEED rating systems, consider Innovation credits and Regional Priority credits to maximize the total LEED points.
- Product transparency will continue to drive industry discussion over the next decade. Consider product transparency in your LEED designs and participate in these discussions.
- The official date for mandatory use of LEED v4 is June 1, 2015 for the U.S. and Canada. Canadian Alternative Compliance Paths are planned to be introduced in June 2014. Before then, projects can continue to register and use LEED 2009.
- Energy and indoor environmental quality continue to play a large role in LEED. Water conservation will continue to increase in importance. Focus on these system efficiencies to reap the most benefit.

Whether or not your project is pursuing LEED certification, green building principals should always be considered and applied. When exercising trade-off methods, better overall environmental outcome should outweigh the desire to accrue LEED points. Finally, I couldn't agree more with the closing comments from the LEED 2009 *Trane Engineer Newsletter*,

"The bottom line goal is more sustainable buildings that are not only good for the environment, but for the society, and your business."

References

- [1] U.S. Green Building Council, LEED v4 impact category and point allocation development process. usgbc.org, last modified August 5, 2013 <http://www.usgbc.org/resources/leed-v4-impact-category-and-point-allocation-process-overview>
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- [4] Stanke D., Murphy J., Solberg P. 2013. ASHRAE Standard 62.1-2010. Trane Engineers Newsletter Live, APP-CMC047-EN

By Chris Hsieh, systems engineer and Jeanne Harshaw, program manager, Trane. You can find this and previous issues of the Engineers Newsletter at www.trane.com/engineersnewsletter. To comment, send e-mail to ENL@trane.com.

March Engineers Newsletter LIVE program

LEED v4. LEED v4 officially launched at Greenbuild 2013. In this 90-minute program, Trane applications engineers will discuss changes in the newest version of LEED and how they impact HVAC practitioners.

Presenters: John Murphy, Mick Schwedler, Charlie Jelen and Chris Hsieh

Contact your local Trane office to register today!

USGBC and LEED v4: As an organization, U.S. Green Building Council (USGBC) celebrated its 20th anniversary in 2013. USGBC continues to advance the green building agenda through policy makers, local and global stakeholders. USGBC's flagship LEED products have been steadily growing throughout the last decade. LEED certified projects have increased to over 13,000 and registered projects surpass 42,000. The number of LEED professionals continue to grow despite the global economic recession.

LEED v4 was approved by 86 percent of the overall vote. The LEED v4 beta program attracted more than 100 projects pursuing certification. USGBC officially released LEED v4 during the Greenbuild 2013 conference and announced mandatory use of LEED v4 on June 1, 2015. This significant date allows the current users of LEED 2009 to complete projects in the existing version and allows time for the project teams to smoothly transition to the new version.

Through an unprecedented six public reviews and over three years of development, LEED v4 is finally here. The features include but are not limited to the following.

- **Address global variance.** LEED v4 rating systems address the global market place by use of metric units and alternative compliance paths.
- **Expand market types.** LEED v4 covers more vertical markets with the same final grade level threshold and whole point structure.
- **Tighten technical rigor.** LEED v4 includes new and more stringent prerequisites and credits.
- **Simplify access.** Online credit library offers a simpler way for the project team to share a specific credit language with each other.

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LEED v4.

LEED v4 officially launch at Greenbuild 2013. In this 90-minute program, Trane applications engineers will discuss changes in the newest version of LEED and how they impact HVAC practitioners.

Applying Variable Refrigerant Flow.

All HVAC systems have their strengths as well as their own set of application challenges. This program will discuss some of the challenges when applying a variable refrigerant flow (VRF) system, such as complying with ASHRAE Standards 15 and 90.1, meeting the ventilation requirements of ASHRAE Standard 62.1, zoning to maximize the benefit of heat recovery and the current state of modeling VRF.

Energy-Saving Strategies for Chilled-Water Terminal Systems.

This ENL will discuss system design and control strategies for reducing energy use in chilled-water terminal systems including variable-speed ECM terminal fan operation, impact of ventilation system design, low-flow chilled-water system design, waterside economizing, waterside heat recovery, and meeting ASHRAE 90.1 requirements.



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Application manuals. Comprehensive reference guides that can increase your application knowledge of a broad range of commercial HVAC systems. The following are just a few examples. Please visit www.trane.com/bookstore for a complete list.

Central Geothermal Systems. Discusses proper design and control of central geothermal bidirectional cascade systems including system piping, system design considerations, and airside considerations. (SYS-APM009-EN, February 2011)

Chilled-Water VAV Systems. Focuses on chilled-water, variable-air-volume (VAV) systems; includes discussion of advantages and drawbacks of the system, review of various system components, solutions to common design challenges, system variations, and system-level control. (SYS-APM008-EN, updated May 2012)

Water-Source and Ground-Source Heat Pump Systems.

Examines WSHP systems components, configurations, options, and control strategies. (SYS-APM010-EN, updated November 2013)



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