Potential Metrics for the ENERGY STAR Climate Controls Program

Background: The Environmental Protection Agency (EPA) shares the excitement of many stakeholders about the wave of innovation sweeping the market for and the savings opportunities promised by advanced HVAC controls. In June 2014, EPA shared with stakeholders the idea of developing a program that would recognize Residential Climate Control Systems (RCCS) based on their energy-saving effectiveness. In such a program, the ENERGY STAR partner would be required to submit periodic anonymized summary data that demonstrates RCCS field savings. In order to develop this summary data, savings from each fielded RCCS would be combined into a summary that is representative of average savings across the product's installed base. In order for the program to be successful, savings calculations must be consistent across RCCS product offerings, calculated using a standardized metric or metric(s). This approach reflects the increasing importance of ongoing services in achieving energy savings from climate controls. It also leverages the capability of connected devices to provide unprecedented data about the use of products once installed in a home. EPA envisions partnering with service providers who have access to that data, and recognizing products that are a combination of hardware and service.

Purpose: EPA is working with stakeholders to develop a standardized metric or metrics that will enable ENERGY STAR recognition of RCCS based on the magnitude of energy savings in the field. As envisioned, such metrics would be able to identify systems that save energy in homes while accommodating quickly evolving technical strategies and business models. RCCSs that are internet connected and have associated services present the opportunity for a different kind of metric, based on data from a large number of installations. EPA seeks a metric that will work well in the context of this large amount of data, leaving aside for the moment the question of exactly how large the group of installations will be or what other considerations might go into choosing it.

Broad Goals and Boundaries: EPA's purpose in developing this metric is to support an ENERGY STAR RCCS program. The ENERGY STAR mark is recognized by most consumers as a symbol of energy savings and product quality, and could serve a valuable role in helping consumers differentiate RCCSs that deliver savings. As a prerequisite to an RCCS program design, EPA must have a credible means of assessing whether consumers save energy and money and of assuring that products represent a good consumer value. Further, EPA's proposed program structure applies only to connected climate controls with a service component whereby a service provider at minimum has access to data from installed units.

Metric(s) shall:

- use only data from the RCCS and data that is publically available, e.g. weather data
- effectively differentiate/rank HVAC field saving attributed to the RCCS
- capture the majority of HVAC energy savings attributed to the RCCS, regardless of the strategy used to achieve savings
- effectively differentiate RCCS attributed HVAC savings when used with all common HVAC system types
- be easy to calculate automatically from machine to machine data

- estimate magnitude of HVAC energy & monetary savings attributed to the RCCS (note: EPA understands the challenge associated with this task and is interested in working with stakeholders to determine paths for doing so)

Assumptions about data availability:

For the purposes of this discussion, EPA assumes that RCCS service providers have access to the following *installation data* for the majority of homes that use their product:

- zip code
- installation date or date enrolled in program
- type, number of stages, and mapping of controlled HVAC equipment to the RCCS
- presence of HVAC sources not under RCCS control (e.g. wood stove, room air conditioner)
- software/firmware version

For the purposes of this discussion, we further assume that RCCS service providers have access to the following *periodic data* for the majority of homes that use their product:

- operating mode, when it changes (cool, heat, fan-only, off, away, vacation, etc.)
- indoor temperature, when it changes by ≥1°F
- set temperature, when it changes by ≥1°F
- outdoor temperature, when it changes by ≥1°F - from online sources
- time-stamped start/stop events for all controlled HVAC sources & stages
- connection status over time

In this effort to seek a credible proxy for HVAC energy savings attributable to the RCCS; EPA has identified two general classes of possible metrics: those based on the run time of RCCS controlled HVAC equipment, and those based on the temperature in the home. Each type has strengths and weaknesses, and each has the potential for refinement. The best choice may combine elements of each. We spend the majority of this paper discussing the two choices. We also briefly consider the supposed gold standard, meter data, and close with some general thoughts.

Note that utility meter data is considered largely inaccessible to RCCS service providers, who would be EPA's partners in any potential ENERGY STAR RCCS program. Thus, metrics that rely on meter data are not being considered. However, datasets that include both RCCS data and meter data are of high interest to help validate considered metrics.

Discussion of Meter Data

Programs to date have exclusively used meter data to assess savings from HVAC controls, so as we contemplate pursuing opportunities opened up by connected controls, we discuss meter data for comparison purposes. The most accurate way to measure HVAC savings would be to consider actual energy use. On the other hand, whole home energy use data would be affected by many other variables besides heating and cooling, for instance if another resident joins the household, hot water use may increase substantially. Distinguishing HVAC savings from premises meter data has been done, but is usually a slow and laborious process and in particular requires meter data from a large number of homes in order to distinguish the signal (RCCS attributed savings) from the noise (everything else that creates variation in energy use). Such an approach is poorly suited to a field with rapid innovation. In addition, current business models of RCCS providers do not all include close coordination with utilities. Until and unless access to meter data (for instance, through Green Button) is easier, EPA considers premises meter data only as a point of comparison, rather than a viable source of data to inform a recognition program.

HVAC sub-metering would mitigate but not eliminate the signal to noise ratio problem, making it easier to distinguish energy savings attributable to the RCCS. In lieu of sub-metering, access to smart meter interval data may allow disaggregation of HVAC consumption from the whole. Disaggregation can be simplified and made more accurate by simultaneous access to RCCS data that indicates start and stop times of each controlled HVAC equipment/stage/speed. On the other hand, looking only at the energy use of equipment controlled by the RCCS risks overlooking compensatory energy use by other sources, such as electric resistance space heaters.

However, in general there appear to be significant barriers preventing both utility access to RCCS data and RCCS service provider access to meter data, because of privacy concerns. In particular, it presents a very high bar for new entrants.

Metric 1. HVAC Run-time

HVAC run time is closely associated with energy use, and can be easily determined from RCCS data. EPA assumes that strategies that RCCS service providers might use to reduce energy use will reduce run time for most types of HVAC equipment. In order to calculate savings for each home, baseline run time that would have occurred without the RCCS must be identified.

Percent Savings Calculation

$$percent\ savings = \frac{RT_{\mathrm{baseline}} - RT_{RCCS}}{RT_{baseline}} * 100$$

where,

$RT_{\mathrm{baseline}} =$ calculated run time at constant comfort setpoint
$RT_{RCCS} =$ actual HVAC run time with RCCS

Energy Savings Calculation

$$\begin{aligned} energy\ savings &= HVAC\ input\ power\ x\ (RT_{baseline} - RT_{RCCS}) \\ &= HVAC\ input\ power\ x\ percent\ savings\ x\ RT_{baseline} \end{aligned}$$

Regarding baselines, EPA is not aware of any generally accepted non-proprietary method of calculating how much equipment would have run at a given constant set point, and presumably would have to develop one as part of the metric development process. We note that because temperature settings are the primary driver for HVAC savings, any method would have to assume settings that would have been used without the RCCS. We discuss these assumptions in detail in reference to temperature-based metrics (pg. 6), and the same considerations apply here.

The accuracy of the energy savings estimate would also depend on how well the rated efficiency (e.g. SEER) reflects the actual installed efficiency over the season for the range of homes in the sample.

The above metric may work well for single stage HVAC equipment, but presents additional challenges for multistage and variable speed equipment. A small but increasing fraction of homes with RCCS will have these more sophisticated systems. For these systems, lowest energy use and greatest comfort generally come from running longer at reduced capacity. To account for this, run time would have to be an average run time, with the run time of different stages weighted by their relative energy use:

$$RT = \text{ weighted average HVAC run time } = \sum_{stages} w_{stage} * RT_{stage}$$

w_{stage} is the relative input power of the stage
RT_{stage} is the run time of the stage

For instance, a heat pump with electric resistance backup heat could be estimated to have a seasonal average COP of 3, in which case electric resistance hours would be weighted by 0.75 and heat pump hours by 0.25 and summed. For a dual compressor AC with compressor capacity ratio of 2:1, the first stage hours would be weighted by 0.67 and the second stage by 0.33 before summing. The baseline calculation would similarly need to be adjusted to calculate a weighted average baseline run time.

Even with weighting, this metric may not accommodate variable speed HVAC; input from stakeholders will be needed in order to determine if there is an opportunity to accurately estimate RCCS savings from variable speed HVAC using a run-time metric. For dual fuel systems, the run time weighting could be based on cost or on GHG impact, and it is likely that separate savings estimates for each fuel would also be useful. Each stage is assumed to have constant relative input power.

Pros:

- Run-time is directly related to energy consumption and is usable to estimate an HVAC system's energy consumption in kWh, therms, etc. if capacity and efficiency rating of the furnace or HVAC equipment is available (BTU/hr & SEER and/or capacity).
- Relatively simple and accurate in determining relative savings for single speed/stage HVAC equipment.
- Captures savings from multiple strategies that an RCCS product may use: encouraging more conservative set points; better control of HVAC equipment (e.g. precooling); encouraging other savings behaviors such as closing blinds on hot sunny afternoons and opening windows on cool evenings.
- Captures the saving that deep setbacks provide for single speed systems; with multi-speed/stage systems, weighting encourages strategies that minimize total energy use.
- Weighted average accounts for relative energy impact of multistage HVAC including electric resistance (backup) heat.
- Can calculate run time separately for heating and cooling if needed.
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Cons:

- No recognized procedure to calculate the baseline.
- In order to do a weighted average, RCCS provider must know equipment types.
- Determining the weighting factors for the weighted average may be difficult.
- More difficult to calculate compared to Savings Degree-Hours (SDH), as discussed next.
- Not currently viable for estimating savings from variable-speed HVAC equipment.
- Baseline requires a customized calculation for each home.
- Need to determine which controlled equipment is included in run time, for instance, fans.

Conclusions:

Developing run-time baselines on a per home basis, using RCCS and weather data appears to be effective for homes with single speed heating and cooling. Although this strategy makes the metric somewhat more difficult to calculate, per-home baselines are necessary for run-time metrics and this approach is vastly simpler than alternatives such as pre-post or randomized control trial (RCT).

Metric 2. Savings Degree-Hours

Service providers employ a variety of algorithms to keep indoor temperature closer to outdoor temperature as a strategy to reduce HVAC energy use. The extent of savings depends on the temperature difference achieved and duration that the temperatures are in effect. The "Savings Degree-Hour" (SDH) metric seeks to measure the extent to which the RCCS shifts indoor temperatures closer to outdoor temperatures and reduces HVAC energy consumption. This metric compares measured indoor temperatures of a home to a reference temperature to quantify the energy savings of an RCCS. During the winter, for example, 5 Savings Degree-Hours would be accumulated when the RCCS lowered the indoor temperature to 65° from the 70° reference temperature for one hour. A large number of SDH indicates a successful RCCS control strategy.

Savings Degree-Hours Calculation

For Heating Hours:

$$SDH_h = \sum_{all\ heating\ hours} (T_{refh} - T_{obs})$$

For Cooling Hours:

$$SDH_c = \sum_{all\ cooling\ hours} (T_{obs} - T_{refc})$$

where,

$T_{refh} =$ reference temperature for heating

$T_{refc} =$ reference temperature for cooling

$T_{obs} =$ observed indoor temperature or set temperature

Energy Savings Calculation

A higher number of SDH corresponds to greater energy savings; however, EPA is not aware of any direct way to estimate energy savings.

The SDH is a new concept but based on simple heat transfer calculations and field research. Numerous studies have observed correlations between a home's HVAC energy use and the inside-outside temperature difference. The SDH metric captures the deviation of temperatures from a reference setpoint, both in terms of degrees and hours. The RCCS seeks to maximize the deviation from the setpoint through a combination of strategies, such as vacancy detection and anticipation based on the home's thermal parameters. The strategies let the inside temperature drift closer to the outside temperature, reduce heat loss/gain and, ultimately, reduce HVAC output.

The SDH relies on two reference setpoints, one for heating and one for cooling. In the simplest case, these reference temperatures would be the same for all homes, regardless of building characteristics and climate. This facilitates comparisons of diverse collections of homes. The reference temperatures could be selected by EPA or based on actual measurements submitted by stakeholders. Service providers could easily calculate each home's SDH because it requires no external information.

The RCCSs with the highest SDH scores would be those where the service successfully encourages residents to keep homes as cold as comfortable during the winter and as warm as possible in the summer. In homes heated by heat pumps, deeper setbacks and faster recovery using backup resistance heating (including baseboard heat) would yield higher SDH scores but proportionately less energy savings because the heat source shifted from the heat pump to electric resistance.

Two identical homes operated in the same manner, but located in different climates, will have different SDHs because the homes respond differently to temperature setbacks and set-ups. A mild winter, for example, will not permit as dramatic temperature reductions (and accumulations of SDHs) from night setbacks as in extremely cold climates. Further, occupants operate their HVAC systems differently in different climates[1], so requiring an identical result may not be realistic.

EPA is not aware of any established way to estimate absolute or percentage energy savings from SDH. Such estimates would probably require simulations of typical buildings. EPA seeks stakeholder thoughts on approaches.

A recent report[2] suggested one type of temperature based metric that may provide a reasonable proxy for energy savings. In this strategy, the reference temperature used would not be the same for every home, but would be based on the setpoint choices of that particular home. It would not then be possible to directly average SDH across many homes, but might be possible to calculate percent savings per home and average that. Doing so would require understanding the HVAC energy savings per degree of setback or setup. EPA is not aware of any method to do so that is well supported by research. Furthermore, it seems likely that the relationship would depend on several factors including HVAC system type.

<u>Pros:</u>

- Captures the majority of savings without spending effort on capturing more minor energy use. Majority of energy savings from RCCS is from changing set points.
- In the simplest case, uses an understandable baseline (the reference temperature) that is the same for each home.
- Provides a distinction between heating and cooling conditions.

<u>Cons:</u>

- Reflects a new concept that will be unfamiliar to consumers and stakeholders alike.
- No existing technique for conversion of SDH to absolute or percentage energy savings.
- Captures savings only from strategies that could impact comfort.

<u>Discussion:</u>

For relative ranking of savings, the SDH metric is straightforward. Data collection could be limited to inside temperature. As such, it should be easy for service providers to adopt. However, it presents some difficult issues, particularly for calculating national savings.

[1] Variability in Measured Space Temperatures in 60 Homes, David Roberts – National Renewable Energy Laboratory, Kerylyn Lay – EnerNOC, http://www.nrel.gov/docs/fy13osti/58059.pdf

[2] Urban, Bryan, and Kurth W. Roth. 2014. *A Data-Driven Framework For Comparing Residential Thermostat Energy Performance*. Cambridge (MA): Fraunhofer Center for Sustainable Energy Systems. Note: this study was sponsored by Nest.

Final Thoughts

The SDH and HVAC runtime metrics are slightly different proxies for energy consumption. SDH captures the building envelope heat losses/gains while the HVAC runtime captures HVAC operation. Each approach has advantages as well as weaknesses and neither fully captures energy consumption. It is possible that a combination of metrics will provide the best proxy.

As we consider each of these metrics, there are several general issues that will apply to both. First, we are conscious of variables other than the RCCS that will affect the results, such as climate/weather, housing type, occupant lifestyle (e.g. is someone home all day?), rate structures, etc. The influence of each of these confounding variables can be dealt with either through normalization or through averaging over a large number of installations. In some cases, these factors may limit whether a particular installation can be considered in the average of metrics.

As examples of how we might deal with specific factors, consider the following cases:

1. Stakeholders have shared with us that it is well understood how to normalize HVAC energy use to weather, for instance in comparing data from one year to the next. Presumably the same techniques could be used in metric calculations.
2. Data sets from installations where the rate structure changes during the period, e.g. from flat rate to time of use, may need to simply be discarded. Since each home is compared to itself on a percentage basis, stable rate structures are assumed to have relatively little influence. (There may be an opportunity to check this assumption over time.)
3. For housing types, we assume that averaging a large number of installations is likely to minimize any effect on the metrics.

For both rate structures and housing types, we also believe that the relevance of the metrics remains, even if confounding effects do not average out completely. Under the assumption that potential new users of a particular RCCS are more similar to current users than to the general population, results generated from current users remain predictive. This principle applies as well to personal characteristics of users, such as their interest in energy efficiency.

Another general question which applies to any metric is whether there should be separate heating and cooling metrics, or metrics separated by fuel type. We raise this question as a topic of discussion with stakeholders.

Lastly, it is notable that we are not certain whether either metric will accurately reflect savings when RCCS are controlling the most sophisticated heating and cooling equipment, most notably variable speed heating and cooling, and zoned systems. EPA sees value in pursuing this program in any case. These systems are a small part of the installed base, and generally have dedicated controllers to take advantage of their efficiency and demand response features. We believe these systems are the future of HVAC, but achieving energy efficiency with systems that are installed now and commonly sold is still an enormous opportunity. Further, EPA expects to learn through an initial program focused on the majority of the installed base and apply learnings to these more sophisticated systems.

EPA Questions to Stakeholders

1. Are EPA's assumptions regarding installation data availability realistic?
2. Are EPA's assumptions about periodic data availability realistic?
3. Are separate metrics needed for heating and cooling?
4. Do the metrics accurately capture savings during times that heating and cooling occur close to each other (or even on the same day)?
5. Which metric will be most credible to consumers? Which is the best proxy for energy savings?
6. Should a metric be expressed in terms of absolute energy (or $) savings, percent savings, or both?
7. Can baseline run times be accurately determined for multiple speed systems?
8. Can you imagine ways your competitors could game the result of each metric?
9. Is there an opportunity for a combined metric that takes advantages of the strengths of both run time and temperature approaches?
10. Does one or both metric(s) capture most or all of the energy savings that advanced climate controls can deliver?
11. Should a single reference (baseline) condition be created for all homes or should a customized reference case be created for each home?
12. EPA envisions service providers would calculate metrics based on (nearly) 100% of their customer base rather than using a smaller representative sample. Is this consistent with RCCS vendor operations or is it administratively burdensome?