Control solutions for air-conditioning, refrigeration and heating & energy efficiency

From a control point of view, the energy efficiency opportunities can be grouped into three approaches:

1. Product-level approach
2. System-level approach
3. Supervision and IoT

Product-level approach

As can be seen from the European Ecodesign policies and the American Energy Star program, to mention just two of the better-known schemes, product efficiency can be improved by enhancing evolutions. These usually include:

- Better insulation (of perimeter walls, for instance)
- Energy recovery, e.g. by heat exchangers or ejectors
- Sensors to measure the controlled variables (temperature, pressure, humidity, and so on)
- Modulating motors, which in turn means modulating compressors, valves, pumps, fans, dampers, or anything driven by a motor
- **Controllers** to bring the product to the set point while at the same time minimising energy input

Schemes that improve product energy efficiency are already generating benefits. According to the European Commission's "Ecodesign Impact Accounting – Status Report 2017", the **Ecodesign policies are projected to save around 16% energy in 2020** (ECO scenario) vs. 2010 (BAU[1] scenario) from the regulated products:

[1] ECO = Ecodesign; BAU = Business As Usual, i.e. with the Regulations existing in 2010

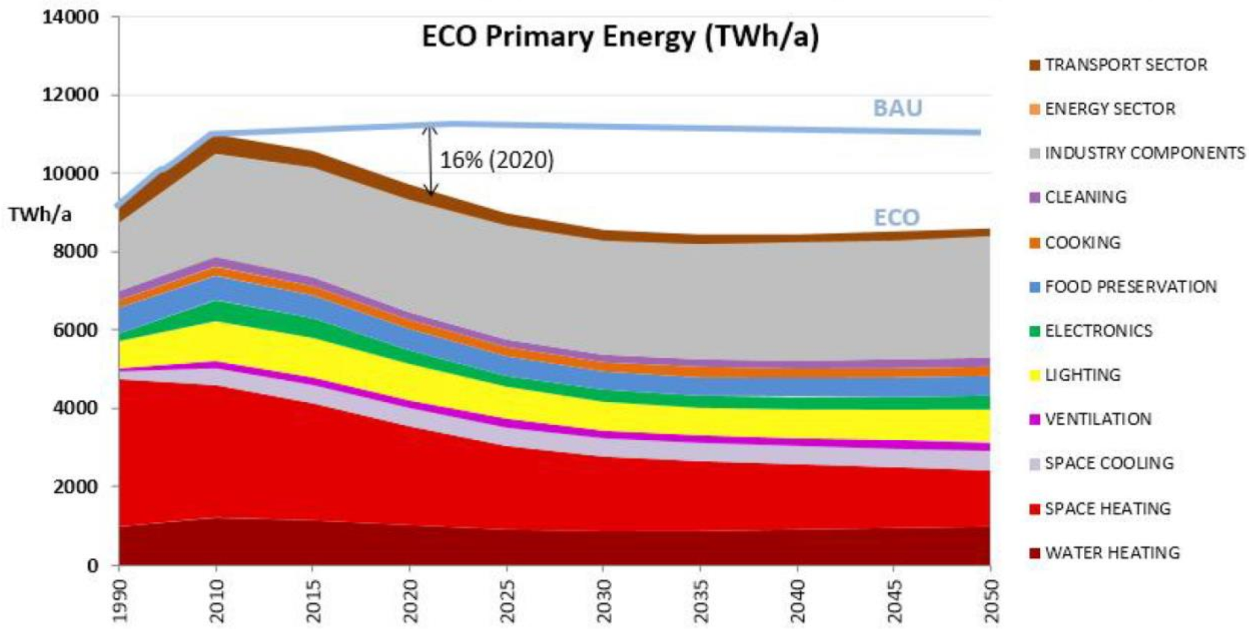


Figure 7. Primary energy consumption of products included in ecodesign impact accounting, status 1 October 2017 (energy sector impact not shown)

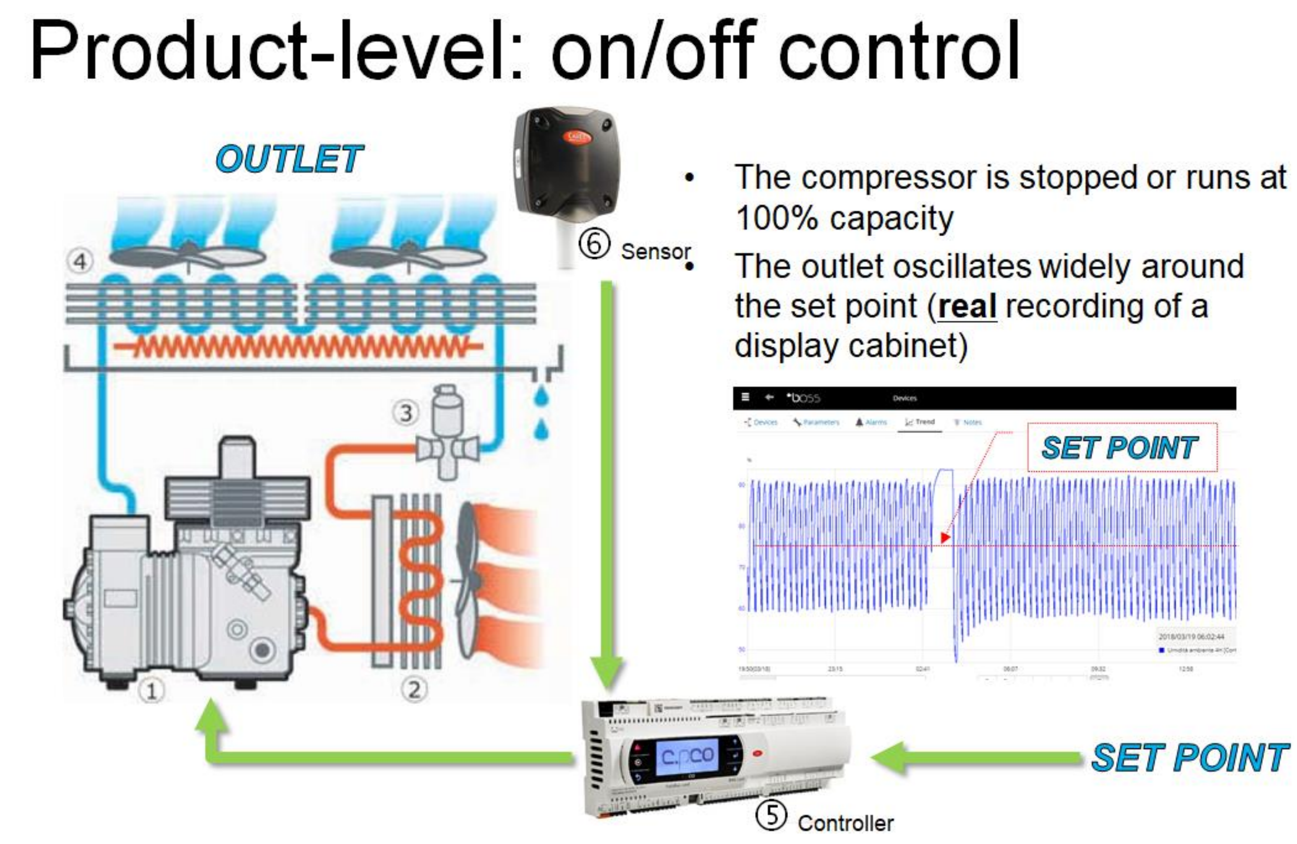
When focussing on the **control aspects**, **modulation clearly accounts for the lion's share** of energy saving, as its aim is for the product to operate **using the minimum amount of energy** required to reach the objectives and to stably maintain the set point.

Stability around the set point within the user-defined tolerances is always more important than energy efficiency, as this ensures **better food preservation**, proper **process control** and improved **comfort**. In general, a product is designed to carry out a certain task, which involves reaching a user-defined set point (temperature, humidity, pressure, or other parameters or combinations of these) and remaining there stably; if this objective is also achieved while minimising energy consumption, all the better!

Through **proper control strategies**, matched with the other energy-saving techniques listed above, **process performance can be guaranteed along with minimum energy input**.

Usually, **closed-loop <u>modulating</u> control brings the best results** in terms of stability and energy saving, as it adapts the product's operation to what is actually needed, no more and no less. This can easily be explained considering a closed-loop on/off refrigerating product and its evolution to a closed-loop <u>modulating</u> product.

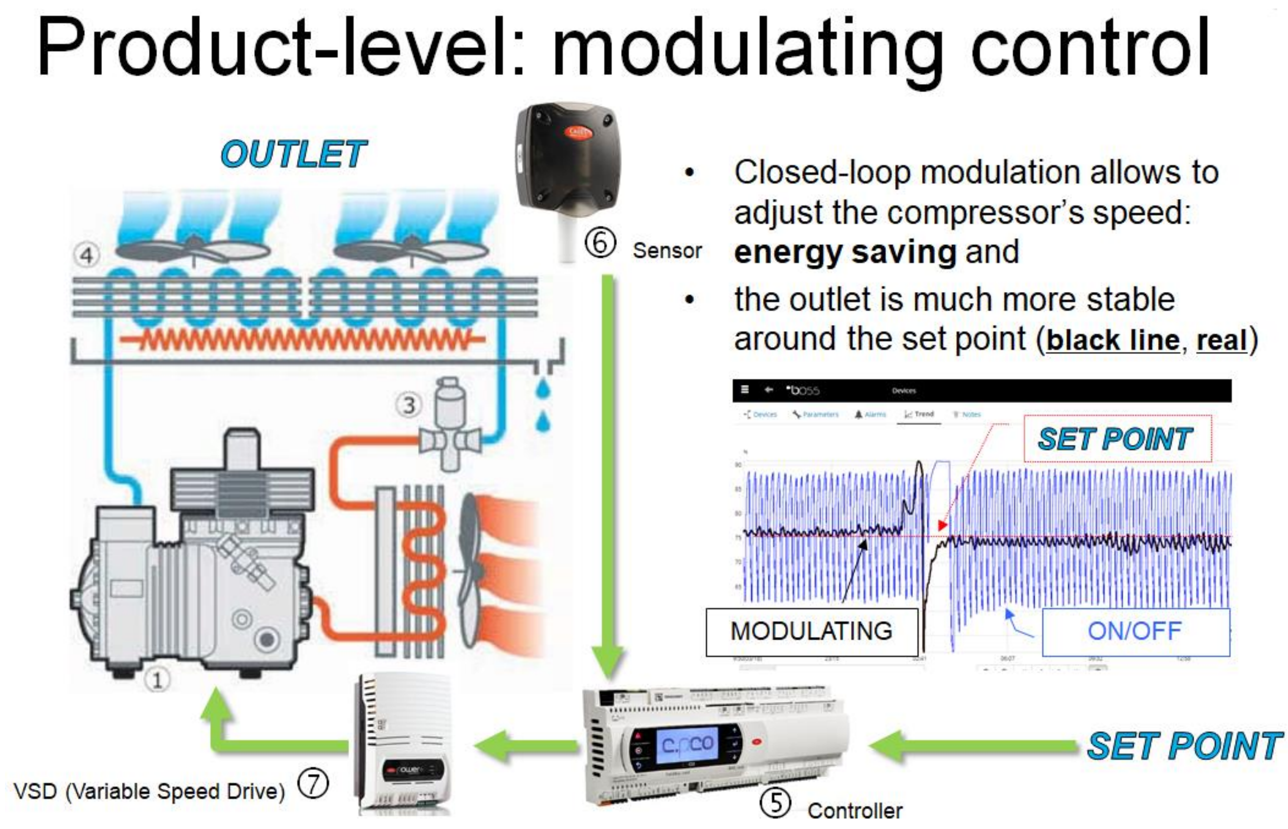
A closed-loop on/off refrigerating product, depicted in the image, starts/stops the compressor at temperatures oscillating around the set point:



If a VSD (Variable Speed Drive, or inverter) is added, stability is achieved as a result of modulation in the closed-control loop.

In the image below, the controller modulates compressor operation so as to stably reach the set point, managing the VSD based on the actual amount of cooling delivered, as measured by the sensor: as soon as the sensor measures that the cooling temperature moves away from the set point, the controller adjusts the compressor speed to bring the temperature back to the set point. The black line on the chart shows how a more stable temperature can be compared to simple (and largely oscillating) on/off control (these are real measurements made inside a retail cabinet).

The superiority of a modulating closed-control loop strategy is clearly evident:



10%-20% energy savings are achievable with a modulating closed-control loop strategy.

Are **additional energy savings** possible?

Yes, by improving product energy performance (provided that this is economically feasible) and/or by adopting a **System-level approach**.

System-level approach

A system is a set of devices working together.

These devices may "cooperate" to reaching the same common objective(s) of the system, or may have individual set points and no system-wide objective(s); in either case, their energy inputs define the energy consumption of the system as a whole.

How much energy can potentially be saved by a **proper system approach**? Considering buildings, which are complex systems of devices influenced both by the outside environment and the occupants, studies[2] suggest that **savings might range between 16% to 49% by combining energy-efficiency measures** (controls, sensors, better products, and others).

[2] Refer to:

- "Optimising the energy use of technical building systems – unleashing the power of the EPBD's Article 8", by ECOFYS and WAIDE STRATEGIC EFFICIENCY LTD., 27th March 2017, EU, Table 24
- "Impacts of Commercial Building Controls on Energy Savings and Peak Load Reduction", by PNNL's report 25985, May 2017, USA, Figure S.2

So, the next question is: how can those savings be obtained while still guaranteeing the set point?

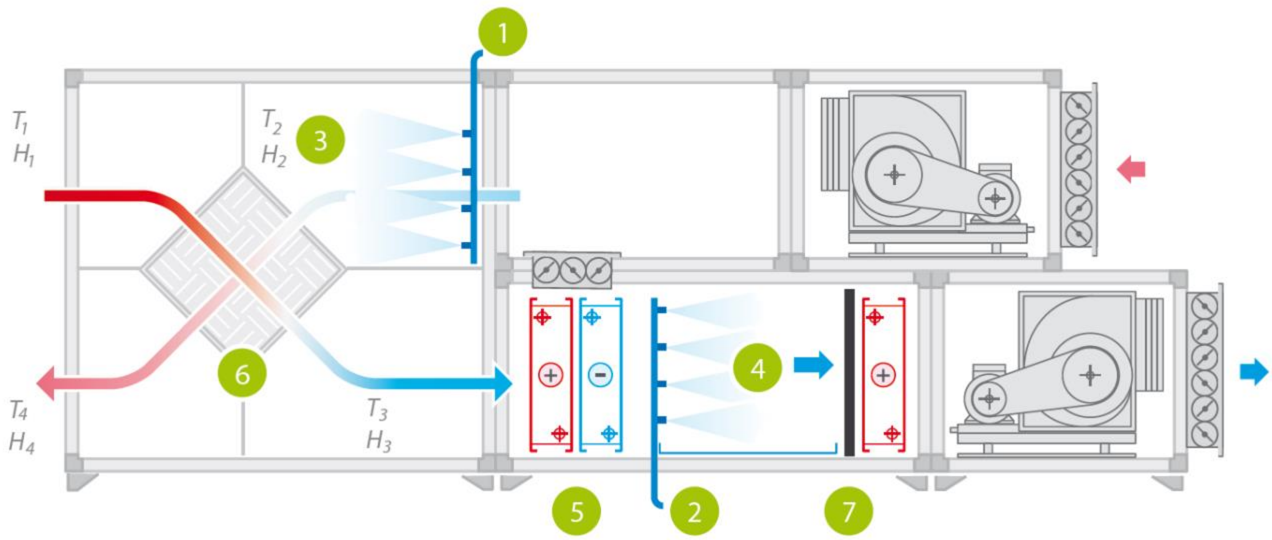
The following two cases need to be addressed separately:

- The system's devices influence each other
- The system's devices do *not* influence each other

<u>The system's devices influence each other</u>

This is the case of AHUs:

- An AHU is a system comprising several devices: coils, humidifiers, etc.
- The AHU has the common objective of supplying air at specific temperature and humidity conditions, flow-rate, etc.
- Each device influences those downstream via the air stream, as the air stream is common to all of the devices. For instance, if the pre-heating coil ⑤ increases its heat output, the reheating coil ⑦ can reduce its; or if the heat exchanger ⑥ recovers more heat from the exhaust air, both heating coils can work less



1 - 2	Pressurised water lines	5	Hot and cold water coils
3	Rack for cooling in summer	6	Heat recovery unit
4	Rack for humidification in winter	7	Mist eliminator

Fig. 2.17 *Possible indirect evaporative cooling system diagram*

(from the book on evaporative cooling)

Systems like these usually have more than one objective. For example, the objectives of AHUs, presented in descending order of importance, may be:

1. Supply air at the user-defined conditions

2. Minimum total running cost for the entire AHU
3. Minimum total primary energy input for the entire AHU (to minimise indirect CO_2 emissions from running the AHU)
4. Minimum total mains water used by the entire AHU
5. Maximum use of outside air

This hierarchy of objectives means that:

1. The supply air set point must be reached first of all
2. Then, device operation can be modulated to minimise the total running cost (while still guaranteeing the supply air set point)
3. Then, device operation can be modulated to minimise the total primary energy input (and again still guaranteeing the above objectives)
4. Then, device operation can be modulated to minimise the total amount of mains water used (and again still guaranteeing the above objectives)
5. Finally, device operation can be modulated to maximise the use of outside air.

When device operation can be modulated, the supply air set point may be reached by adopting more than one combination of device operating conditions; of all these combinations, those that minimise total running cost can be chosen; then of these, the combinations that minimise total primary energy input can be chosen; and so on, continuously reducing the available combinations of operation until all of the objectives have been satisfied.

This plainly explains the importance of using modulating devices when the devices influence each other.

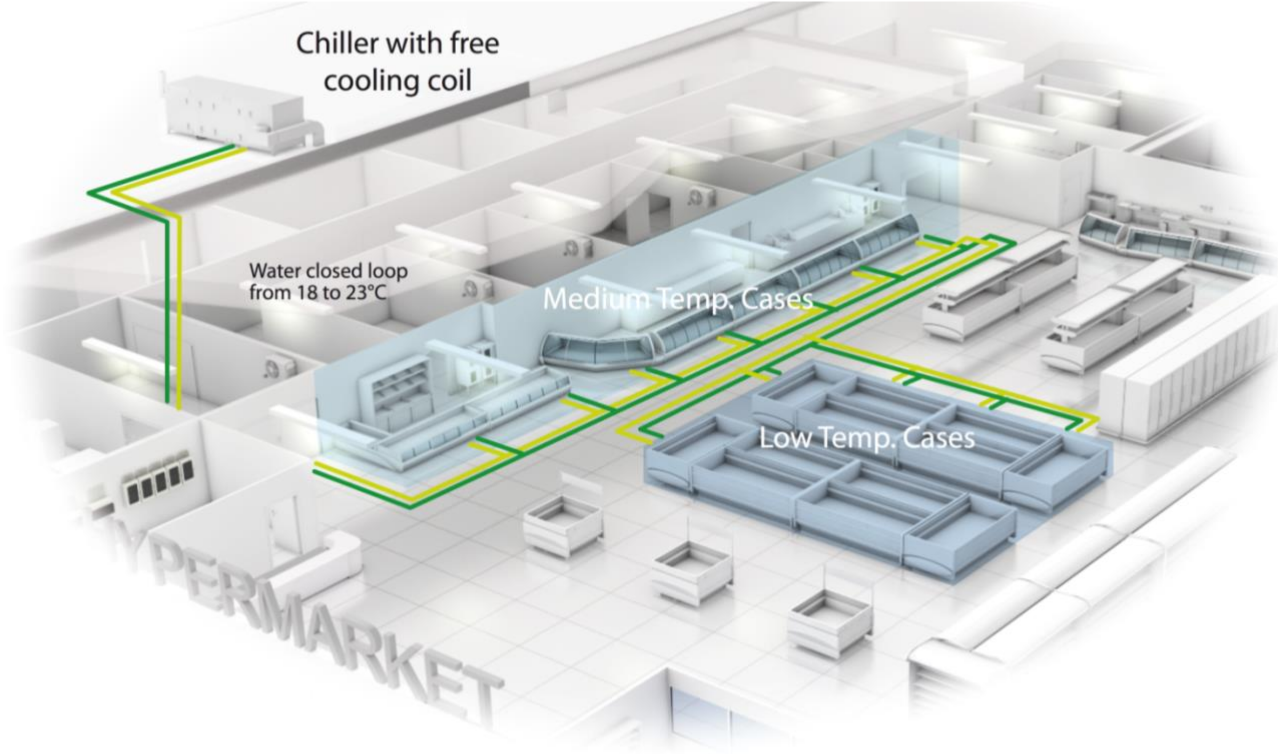
It also highlights how even more important is, in such systems, for the system controller to be able to define individual product set points based on the system objective(s), the primary rule for defining the individual set points being that the *combination* of device outputs best guarantees all of the system objectives. As a consequence of this primary rule, the individual set points will not necessarily mean the devices operate at the minimum output needed to reach the system objectives: on the contrary, it may be necessary to operate some of them at levels above their minimum energy input in order to accomplish the system objectives. Generally, in fact, at a system level, **the system's objectives may require non-minimum set points at a device level**.

The system control software must therefore be designed according to this philosophy. In particular, the control software will need to define the individual set points for the devices making up the system, so as to guarantee the system objective(s), or, at least, get as close as possible in case some devices were undersized. This usually leads to a control strategy that is more complex than with systems comprising non-influencing devices.

<u>The system's devices do *not* influence each other</u>

This is a much easier scenario: as the devices do not influence each other, they can reach their own set points by reducing their duty cycle to the minimum required and, at the same time, minimising the system's total energy input.

Water-loop-based semi plug-in display cabinets constitute a perfect example.



Semi plug-ins **do not influence each other as each rejects heat into the heat sink represented by the water loop**: as long as the water is kept at the right temperature for each display cabinet, each cabinet will not be influenced by the heat rejected by the others, so all of them will **independently modulate their operation based on their own individual set points**, **minimising** both individual and overall energy input, i.e. **the system's total energy input**.

In this case, the device controllers are as important as, if not more important than, the system controller.

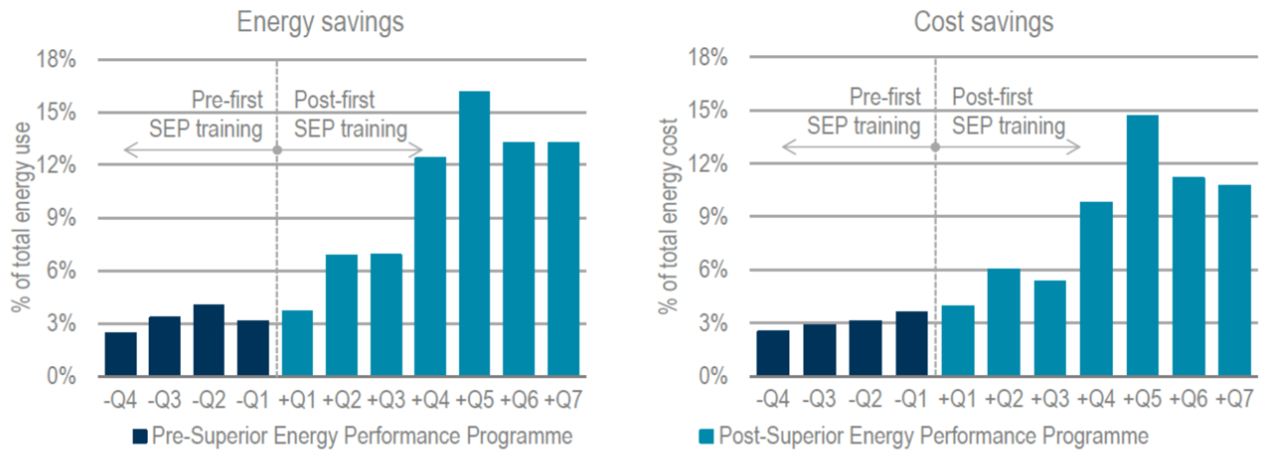
Note that a traditional retail system, where the MT and LT cabinets are connected to common refrigerant circuits, is an example of the first kind of system, where the cabinets influence each other. In other words, **water-loop-based semi plug-in display cabinets make up a refrigerating system which has a number of advantages over a traditional retail system also from a system control point of view**, and not only as regards ease of installation, lower refrigerant charge and TEWI.

Supervision and IoT

At a higher control level, supervisors and IoT come into play.

Supervisory systems are used to track the behaviour of products and systems, reporting and highlighting conditions that may bring improvements (so-called "descriptive analytics"). One interesting finding from this point of view is the work by the International Energy Agency that shows how energy management systems (EMSs) can help reduce energy costs even by > 10% when properly applied by trained personnel:

Figure 3.10 Verified average quarterly energy and associated cost savings from implementation of the ISO 50001 energy management system



Source: LBNL (2015a), *Development of an Enhanced Payback Function for the Superior Energy Performance Program*, http://aceee.org/files/proceedings/2015/data/papers/1-72.pdf.

In the mid-term future, IoT will help improve the efficiency of complex systems by shifting from "descriptive analytics" to "preventive analytics" (i.e. predict what might happen), "prescriptive analytics" (i.e. propose operational/strategic solutions based on the analysis performed), and even "proactive analytics" (i.e. automatic implementation of the proposed actions).

Conclusions

Product efficiency can further be increased by state-of-the-art solutions, with clear economic and ecological advantages; however, the improvements may become not convenient if they are already close to their respective maxima. It is a natural consequence, then, that the coordination of products acting as a system becomes more and more prominent in order to minimise their direct and indirect emissions as well as the overall running cost. From this point of view, system-level controllers, energy management systems and the IoT will play a prominent role in driving the heating and cooling systems.