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Generating heating billing using smart thermostatic valves

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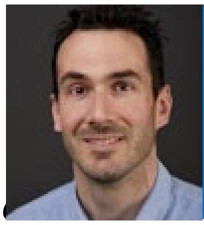

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Summary

Using advanced technologies to enhance the energy efficiency of residential buildings, CSEM has developed an advanced, data-driven approach to compute radiator heating estimations via the SMINTEBI system, which utilizes their newly developed algorithm and relies on ‘smart’ thermostatic valves. This patent pending approach is not only **cost-effective** but also generates **accurate and reliable heating bills**. Additionally, this smart technology can be **app-controlled** providing the user with the flexibility to set **daily and vacation schedules** for better energy budget management.

How are heating bills currently generated?

Many tenants are still billed proportionally to the total floor area of their apartment. In this situation, tenants are not billed in terms of individual consumer behavior but via a standardized calculation applied to all the users, which reduces their incentive to adopt energy conservation measures. To combat this issue, Individual Tenant Billing (ITB) has been introduced, making users individually accountable for their energy consumption. In the case of buildings equipped with radiators, which represents most of the European building stock, enabling ITB typically involves equipping centrally heated radiators with a heat cost allocator (HCA, illustrated in Figure 1). The HCA estimates energy consumption using the EN442 standard, which considers the room and radiator surface temperatures as well as radiator coefficients that are obtained in a controlled environment. There are several factors, however, that influence the HCA estimation accuracy, which are linked to the fact that the radiator coefficients vary with respect to operational conditions. These variations include[1]:

1) Installation and commissioning: position with respect to wall, floors and proper commissioning
2) Obstructions: the presence of furniture, shelves or curtains
3) Operating condition: varying thermo-fluid conditions (flows and temperature)
4) Radiator condition: the presence of mud or other debris

It is possible to eliminate these issues by taking a direct energy measurement using a heat meter (based on flow and temperature measurements). Financially, however, adapting this approach to radiators is both costly and impractical, as it requires the retrofit of multiple sensors to each individual radiator.

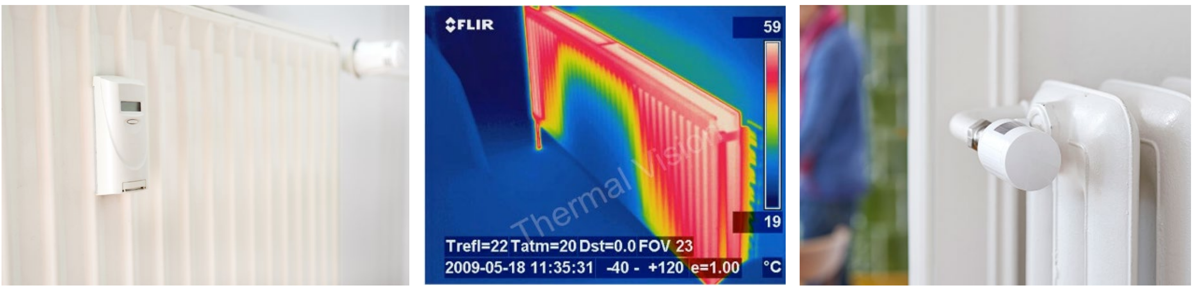

Figure 1: Heat cost allocator (left), infrared image of a radiator clogged with mud (middle) and smart thermostatic valve (right).

[1] Arpino F. et al., “Influence of installation conditions on heating bodies thermal output: preliminary experimental results”, 71st Conf. of Italian Thermal Machines Engineering Association, 2016, Turin, Italy

How can the SMINTEBI approach improve the current situation?

SMINTEBI, which stands for **SM**art **IN**dividual **TE**nant **BI**lling, relies on smart thermostatic valves (STV, illustrated in Figure 1) to estimate the radiator energy. The proposed new approach shows the following advantages:

1) Automatic and continuous estimation of radiators' coefficients, resulting in facilitated commissioning and reduced heat allocation estimation errors.
2) Reduction of installation and operation costs, as the STV serves as a replacement for both the thermostatic valve and the HCA.
3) Provision of additional services as the STVs can also be exploited to reduce heating needs e.g. day/night temperature set-points or control of on-demand vacation mode etc.

The operational concept of the SMINTEBI system is illustrated in Figure 2. The system is composed of:

1) Smart thermostatic valves (STVs) that continuously measure the valve inlet temperature directly at the radiator, as well as the room temperature.
2) A single heat meter (HM) that measures the overall consumed energy of all the radiators connected to the system.

Each individual radiator's energy value is calculated by the patent-pending SMINTEBI algorithm, based on state-of-the-art machine learning techniques. This eliminates the need for an extra sensor to compute the mean radiator temperature (as it is the case for HCAs). Additionally, the system's robustness is ensured by its ability to adapt to the different factors that can affect a radiator's coefficients. Resultantly, SMINTEBI's reliable radiator energy estimation means tenants are issued with precise heating bills that more accurately reflect their energy consumption behavior.

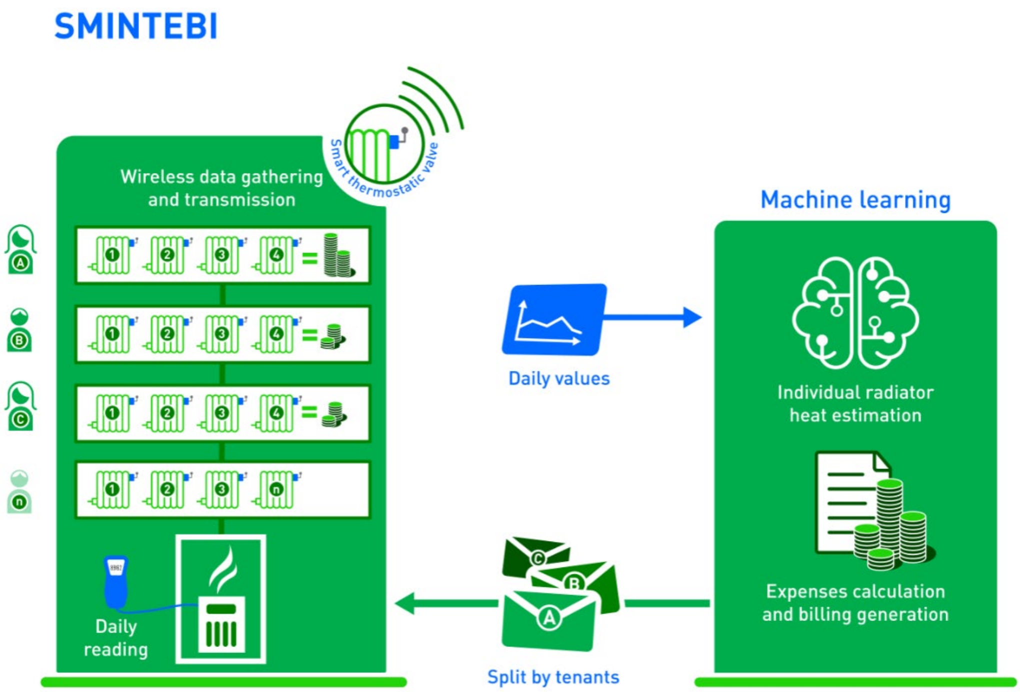

Figure 2: SMINTEBI heat allocation method overview

How does SMINTEBI compare to standard heat allocation methods?

In order to assess the quality of the heating bills generated by SMINTEBI, a relative heat allocation error for apartments was defined. This quantity represented the heat allocation error (in %) on a given group of radiators (typically an apartment) compared to the ground truth (a calibrated heat meter, for instance). This error indicates whether or not the heating bill correctly reflects the consumed energy. In order to quantify the quality of the method across several apartments, the mean absolute percentage error (MAPE) of the heat allocation was used hereafter[2].

SMINTEBI was evaluated across two different scenarios:

1) **A calibrated radiator test bench:** located at the National Italian Research Institute for Metrology (INRIM, Italy) and composed of 40 radiators of different types, each equipped with an individual heat meter/HCA. In this test, the MAPE measured at 4.0% for the HCA and **2.7% for SMINTEBI.** In consequence, SMINTEBI reduced billing error by almost 40% – an impressive figure considering this test was performed under controlled conditions[3].
2) **A four-floor multi-family house:** located in the city of Neuchâtel (Switzerland), this site was chosen to test SMINTEBI in a real environment and under real conditions. In this setting, SMINTEBI's success was even greater, with the MAPE measured at 12.5% for the HCA and **6.7% for SMINTEBI** – reducing billing error by 50%. This building's heating system was approx. 20 years old and consequently variations to the radiator's coefficients were likely to have occurred.

The test results, which are illustrated in Figure 3, clearly demonstrate the improvement for both scenarios brought by the SMINTEBI system with respect to conventional HCAs. Moreover, The SMINTEBI system performed considerably better in the second test scenario, which is representative of real-life conditions. This clearly showcases the SMINTEBI system's ability to identify and adapt to the factors that affect radiator coefficients, something conventional HCAs cannot do.

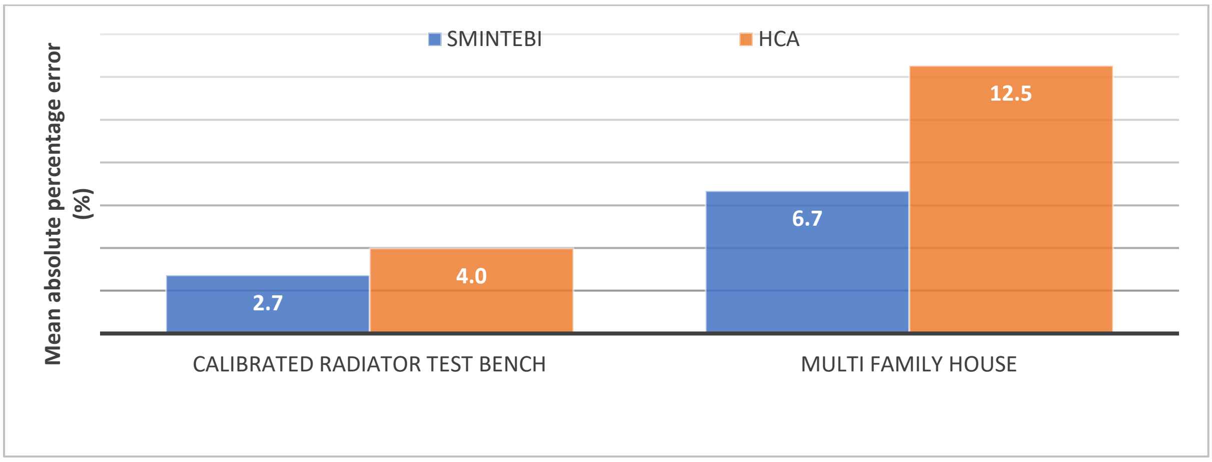

Figure 3: mean absolute percentage error (MAPE) of the calibrated radiator test bench and multi-family house.

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[2] For a quantity X_i the mean absolute percentage error is defined as : $MAPE = \frac{100}{K}\sum_{i=1}^{K}\left|\frac{X_i - \hat{X}_i}{X_i}\right|$, where $\hat{X}_i$ is the estimated value of X_i

[3] The details can be found in: Saba F. et al, An adaptive method for indirect heat accounting in residential buildings in Energy and buildings, to be submitted in 2020