Effect of the Time Interval Base on the Calculation of the Renewable Quota of Building in an Alpine Context

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Abstract

The European goal of decarbonization drives design toward high-performance buildings that maximize the use of renewable sources. Hence, the European RED II Directive (EU, 2018) and the Italian decree (DL 8/11/2021) raise the minimum renewable share in new buildings and major renovations. In this framework, an air-source heat pump (ASHP) combined with an on-site photovoltaic system (PV) is one of the most popular solutions. However, the effectiveness of this heating system in mountainous contexts is not taken for granted, since the harsh climate induces both an increase in heating requirements and a deterioration of heat pump performance. For these reasons, energy simulation is a useful tool for understanding energy behavior and evaluate strategies to ensure the best energy savings. Currently, the renewable quota verification involves a quasi-steady state calculation on a monthly basis. However, this implies the use of the national grid as a battery through the net metering mechanism. The actual share of renewable coverage in the absence of expensive electric storage will necessarily be lower. This work analyzes the actual renewable share achievable in a new building in a mountainous area. Five representative locations in the province of Trento were initially identified through a cluster analysis. The renewable share was evaluated through a coupled dynamic simulation of the building and the energy systems. The results show how the calculated renewable share in this building changes according to the time interval used to close the balance with the grid. The evaluation of the renewable quota (QR) was carried out not only closing the balance by the hour or sub-hour but also by the month.

1. Introduction

Despite the recent increase in efficiency investment, the International Energy Agency (IEA, 2021) states that buildings' lifecycles are responsible, directly and indirectly, for about 37 % of global energy and process-related CO_2 emissions. According to the European Directive 2018/2001 (EU, 2018) and to Legislative Decree n.199/2021 (DL 8/11/2021), heat pump and renewable equipment deployment seems to be one of the most effective and the most economical solutions for reducing buildings' carbon footprint.

In the absence of electric batteries, a certain level of the renewable share is assured by the direct use of the PV production for heat pump operation. Nevertheless, the mismatch between the solar availability (during the day) and the building energy demand (mostly during the evening) is one of the main challenges to reach a high renewable share. Different solutions have been studied in the literature to increase the renewable quota of the system, such as energy storage and control strategies to match the building load to the solar availability (Fisher et al., 2017; Luthander et al., 2015). In (Pinamonti et al., 2020) the authors showed how the use of simple rule-based controls can lead to the reduction of up to 17 % of the energy withdrawn from the grid. Similarly, in (Franzoi et al., 2021a), the benefit of renewable energy communities in self-consumption of PV production emerges. What is not yet clear is whether the mandatory limits on renewable quotas are achievable without these measures. Moreover, the regulation currently provides for the calculation based on balance closure on a monthly basis, thus ensuring within the month the possibility of balancing between the

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energy delivered in the central hours of the day and that withdrawn during the night, in a net metering scheme. Another research question therefore involves how much the real self-consumption of renewable energy of buildings that comply with the regulatory constraint in the absence of net metering and expensive electric batteries is.

This work therefore focuses on the analysis of a new residential building equipped with a low temperature heating system, thermal storage and a heat pump coupled with a PV system.

The single-family building (MF) analyzed represents a typical Italian building (Capozza et al., 2014), whose thermal properties meet mandatory constraints for new construction or major renovations.

2. Methodology

This paper studies the energy behavior of the MF building, to estimate the renewable quota. The goal is to verify whether the minimum share (DL 8/11/2021) of total primary energy covered by renewable primary energy is also achievable in a mountain context. The building and the HVAC systems are modeled in (TRNSYS v.17), as shown in the figure below.

2.1 Climate Conditions

The paper specifically analyzes the Alpine climate context of northern Italy. Five municipalities were selected by (Ceccolini et al., 2020), as a result of a clustering of the climate data of the municipalities of Trentino, in northern Italy (Fig. 2). Trento is located in the Italian climatic zone E, with heating degree days from 2101 Kd to 3000 Kd; while the other municipalities are in zone F, with heating degree days over 3001 Kd (DPR 412/93).

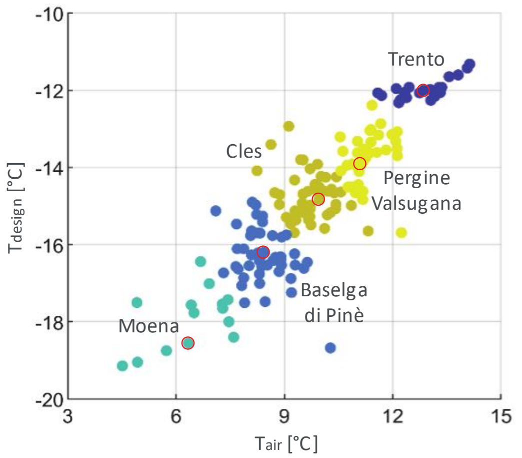

Fig. 2 – Identification of the 5 clusters of Trentino municipalities from the analysis of the average annual temperature and of the design temperature

Climate data are those of UNI 10349-1:2016 standard (UNI, 2016a), but for locations not included in the list, the solar irradiation of the nearest main city is assumed. Pergine Valsugana and Baselga di Pinè are related to Trento, whereas Cles and Moena are nearest to Bolzano.

Table 1 – Climatic data for the 5 municipalities of Trentino

Cluster	Municipalities	Lat	Alt	T_{design}	T_{air}
1	Trento	46.04	194	-12	12.9
2	Pergine V.	46.04	482	-14	11.4
3	Cles	46.22	658	-15	10.1
4	Baselga di Pinè	46.08	964	-16	8.8
5	Moena	46.23	1184	-18	6.4

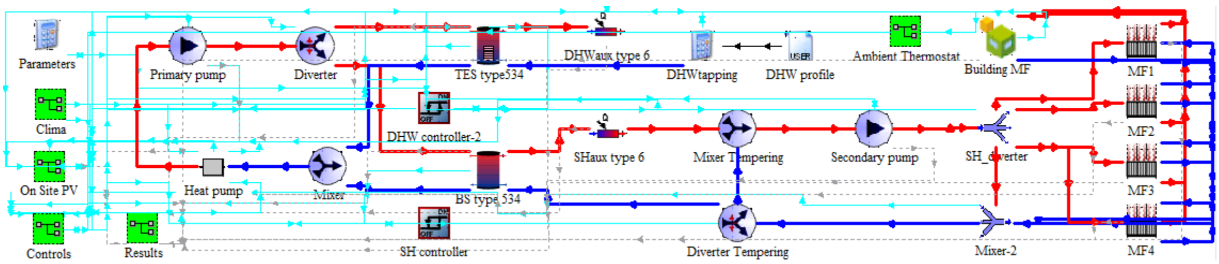

Fig. 1 – Layout of the developed TRSNYS model

2.2 Case Study Building

The MF building is composed of 2 floors, each with an area of around 88 m². The thermal characteristics are close to the limits of transmittance required by the current local legislation (DPP 13/07/2009). To reach a high-performance level, the building has 15 cm of extruded polystyrene (EPS) insulation on the external walls, 12 cm on the roof and well-insulated windows. The 4 thermal zones, 44 m² each, are identified by splitting the building along the west to the east axis in order to have uniform solar gains in the zone.

Table 2 presents the geometrical characteristics and the thermal properties of the building.

Table 2 – Geometrical characteristics and thermal properties of the single-family building

Geometrical characteristics		MF
Floors	/	2
Apartments	/	1
A_{FloorL}	m²	104.86
A_{FloorN}	m²	87.99
VolumeN	m³	527.91
$A_{w,N}$	m²	8.4
$A_{w,S}$	m²	8.4
$A_{w,E\text{-}W}$	m²	8.4
Height/1 floor	m	3
Thermal properties		**MF**
U_{foor}	Wm⁻²K⁻¹	0.366
U_{wall}	Wm⁻²K⁻¹	0.183
U_{roof}	Wm⁻²K⁻¹	0.225
U_{window}	Wm⁻²K⁻¹	0.8

2.3 HVAC System

The HVAC system (Fig. 3) consists of an inverter-driven heat pump (HP), a buffer storage tank (BS) for space heating (SH), and one for thermal energy storage (TES) for domestic hot water (DHW) preparation. The heat pump has a rated capacity of 7.18 kW for source temperature 7 °C and sink 35 °C. The emission terminals for SH are radiant panels fed with an inlet temperature of the hot water of 35 °C in the design conditions. The supply temperature to the radiant panels, as well as the BS and the HP setpoint temperatures, are controlled by an outdoor reset control. The setpoint temperature of the TES is 50 °C. The temperatures of the BS and TES determine the activation of the heat pump and are controlled by a proportional control.

The building is also provided with a photovoltaic system, inclined 20° on the south pitch of the roof. There are 7 modules connected in series, resulting in a peak power of 2.94 kW and an overall area of 12 m² (i.e., roughly 12.5 % of the roof surface).

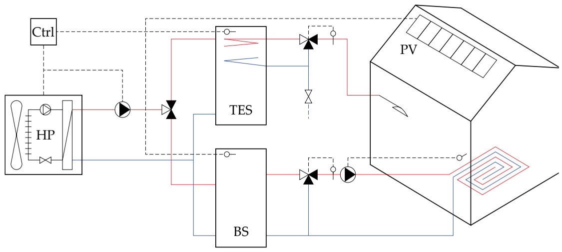

Fig. 3 – Heating system

2.4 Control Strategy

The single-family building is analyzed with and without self-consumption (SC) maximization strategies.

In the first scenario (*bas*), there is no advanced control strategy. A basic control is used, whereby the thermal storages are fully charged when a temperature set-point change occurs.

In the second scenario (*enh*), a rule-based control strategy (RBC) is adopted to maximize the SC of PV generation. The BS and TES set-points are raised, in case of PV energy surplus. This strategy, for inverter-driven air-to-water heat pump, was proposed by (Pinamonti et al., 2020).

2.5 Renewable Primary Energy Quota

Although the dynamic energy simulation uses a time step of 1 minute, the calculation of the renewable energy quota is performed closing the balance on a monthly basis (Eq. 1), according to the Italian standard (UNI 2016b). In addition, Eq. 2 and Eq. 3 show the calculation of the renewable quota closing the balance on an hourly basis, according to the current net metering scheme, and on the minute (i.e., the time step), respectively.

$$QR_{mo.} = \frac{\sum_{months} \min(\int_{mo.} Load\,;\int_{mo.} PV)}{\sum_{months} \int_{mo.} Load} \quad (1)$$

$$QR_{ho.} = \frac{\sum_{hours} \min(\int_{ho.} Load\,;\int_{ho.} PV)}{\sum_{hours} \int_{ho.} Load} \quad (2)$$

$$QR_{mi.} = \frac{\sum_{minutes} \min(\int_{mi.} Load\, ; \int_{mi.} PV)}{\sum_{minutes} \int_{mi.} Load} \quad (3)$$

3. Results and Discussion

This section presents the results of the dynamic simulation, for both scenarios. The analysis performed allows an understanding of the extent to which the different interval affects the QR. Furthermore, the results are represented according to the different site elevations, thus showing the role of climate severity.

3.1 Annual Renewable Quota (*bas*)

The calculated quota of renewable energy over the total primary energy increases by 12 % ÷ 17 % in the 5 locations, changing the balance closure interval from a minute to a month (Fig. 4). This shows how the regulatory constraint of 60 % (monthly basis), with no storage batteries, corresponds to an actual renewable share of about 50 %.

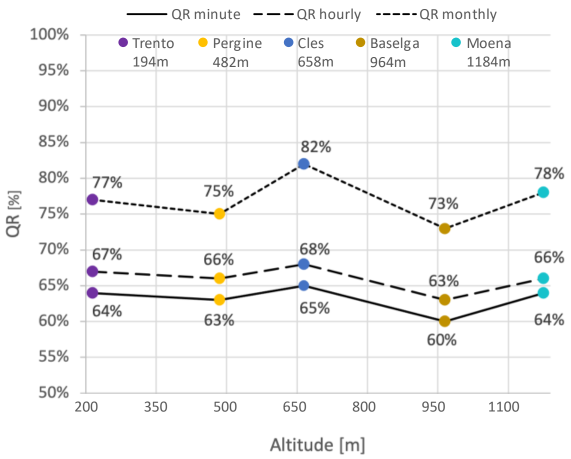

Fig. 4 – Annual values of QR minute, QR hourly and QR monthly: TRNSYS results for the MF building (*bas*)

The hourly and minute calculation has almost similar values with less marked deviations. The differences are much more evident if QRminute or QRhourly is compared with QRmonthly. Between the monthly renewable share and the minute one there is an average difference of about 13 %. The greatest difference is in Cles, Baselga and Moena, the municipalities with a harsher climate.

The renewable share calculated on a monthly basis is obviously greater than that on a minute basis, because the assumed on-site exchange allows the grid to be used as a virtual battery (within the month).

It can be noted that the percentage of QR decreases as the altitude of the municipalities increases, and, consequently, the design and the outdoor air temperature is lower. However, two anomalous behaviors are found for Cles and Moena. This is due to the higher solar radiation (UNI, 2016a).

3.2 Self-Consumption (*bas*)

Figs. 5 to 9 present the comparison between the monthly load profile (blue bars) and PV generation (orange bars) and the self-consumed energy based on a one-minute balance (yellow bars). The representation is made for each climate analyzed. In addition, the graphs show the self-consumption factor (SCF) and load coverage factor (LCF). The former is defined as the ratio of self-consumed PV energy vs the total PV energy generated. LCF, on the other hand, represents the fraction of PV energy used over the electricity absorbed by the HP and auxiliary systems. The LCF index differs from QRminute because it estimates only the renewable electricity share, neglecting both the renewable electricity taken from the grid, as well as the air source energy of the HP.

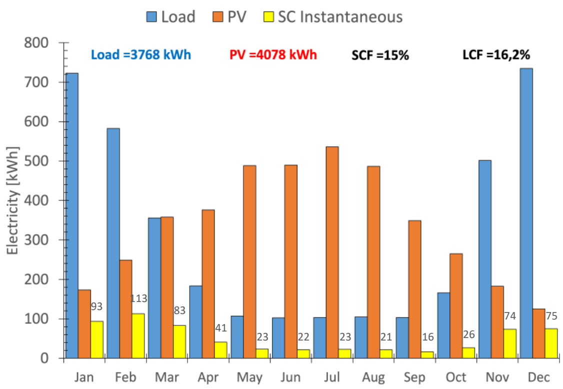

Fig. 5 – Energy profiles and SC minute based on Trento (*bas*)

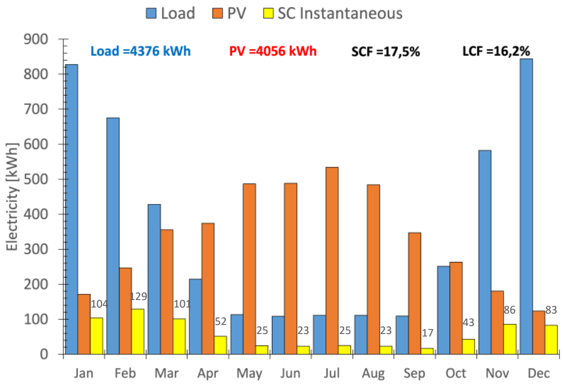

Fig. 6 – Energy profiles and SC minute based on Pergine (*bas*)

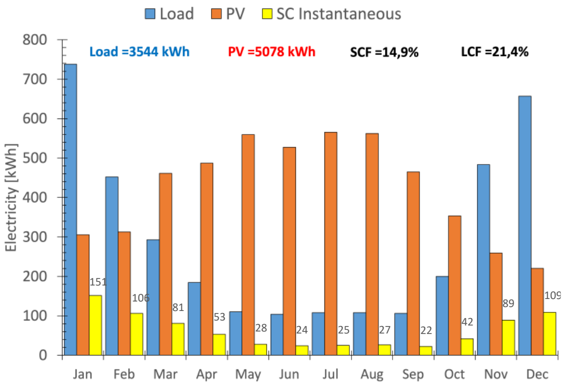

Fig. 7 – Energy profiles and SC minute based on Cles (*bas*)

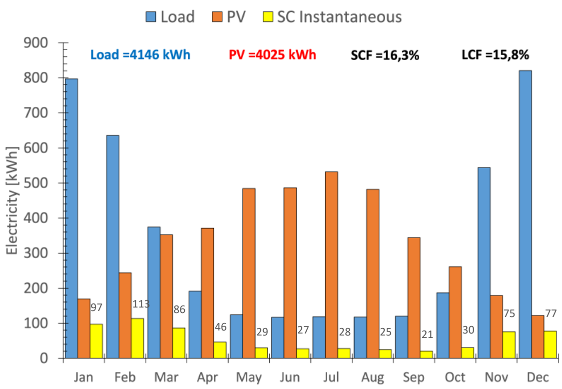

Fig. 8 – Energy profiles and SC minute based on Baselga (*bas*)

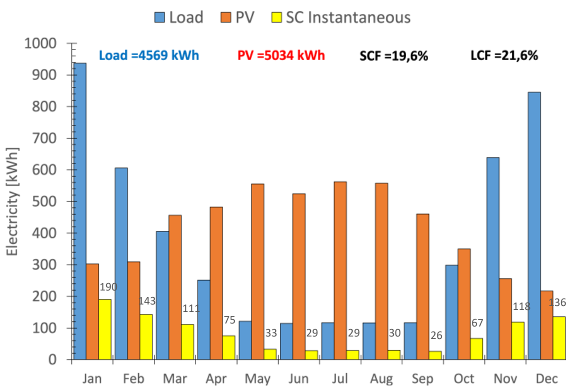

Fig. 9 – Energy profiles and SC minute based on Moena (*bas*)

Obviously, the load profile does not coincide with that of PV production. The largest gains from PV are during the summer period and during the daytime. This contrasts with the monthly demand profile and the daily habits of households, which consume more in the evening hours.

If self-consumption based on a monthly balance were shown, in summer, the yellow bar would coincide with the blue bar (self-consumption equal to load) and, in winter, with the orange one (self-consumption equal to PV generation). As already mentioned, closing the balance with an interval of a month implies balancing between the energy injected into the network in the central hours and that taken during the night in a net-metering scheme, that is, exploiting the grid as a virtual battery, albeit with the constraint of using all the stored energy within the month.

By calculating the actual SC of renewable energy, in the absence of net-metering and electric batteries, lower renewable quotas would be achieved.

As shown in the graphs, SCF ranges from a minimum of 15 % to a maximum of 20 % (17 % average), while LCF ranges from 16 % to 22 % (18 % average). The highest values are obtained in Moena. High LCF and SCF values mean that the electricity load is mostly covered by PV panels.

3.3 Annual Renewable Quota (*enh*)

To increase the SC, in the second scenario, the rule-based control strategy is applied. Comparing the results in Fig. 10 with those in Fig. 4, QRminute and QRhourly increase, while QRmonthly decreases.

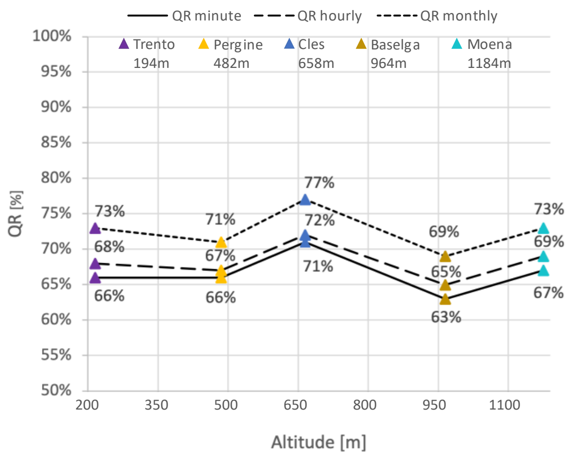

Fig. 10 – Annual values of QR minute, QR hourly and QR monthly: TRNSYS results for the MF building (*enh*)

The graph firstly highlights a lower variability (5 % ÷ 7 %) between the QR evaluated on a monthly basis compared with the minute-evaluated QR. This demonstrates the ability of the adopted control in optimizing the use of the PV generation.
QRminute improves by about 3 % because the instantaneous consumption of PV energy rises, and grid withdrawal decreases by about 4 %. In contrast, the QRmonthly decreases as rule-based control results in an increased load (Figure 11). However, in the monthly balance calculation all the PV production was already self-consumed also in the *bas* scenario, since the grid acts as a battery. Therefore, the higher load of the rule-based control corresponds to a higher withdrawal from the grid and, consequently, to a QR decrement.
Summing up, the difference between the instantaneous values and the monthly one is lower. In the first scenario, the gap is about 13 %, while in the second one, it is about 6 %.

3.4 Self-Consumption (*enh*)

Figure 11 shows the effects of the enhanced control strategy (*enh*) for the municipality of Trento. Compared with the *bas* scenario (Fig. 5), the profile of instantaneous self-consumption changes.

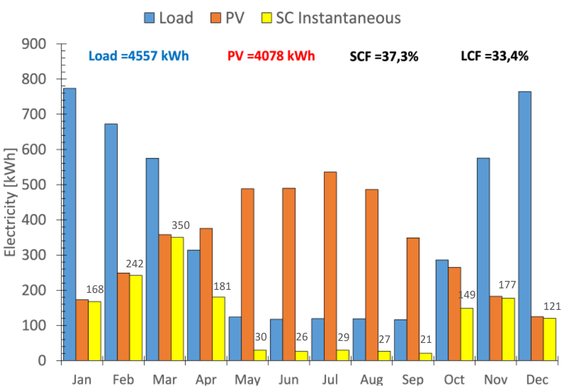

Fig. 11 – Energy profiles and SC minute based on Trento (enh)

The PV generation remains the same, since the system has not been upgraded, but improved. On the other hand, consumption increases slightly (from 3768 kWh to 4557 kWh) due to the control system. The demand profile rises simultaneously with the increase in self-consumption of the energy produced. With the basic control strategy, SCF and LCF are 15 % and 16,2 %; while with the rule-based control are 37.3 % and 33.4 %. This then demonstrates the capability of the control to directly use the PV production, reducing power exchange with the grid.

3.5 Discussion

As the results show, the interval used for balance closure greatly affects QR value. This is especially true if enhanced control strategies aimed at maximizing self-consumption are not employed. However, these enhanced controls are not (currently!) rewarded by the calculation method adopted by Italian law. However, the ongoing changes on the billing scheme for electric power that will soon introduce the hourly based balance calculation will undoubtedly reward the enhanced control scheme with a reduced energy cost.
Looking at both scenarios (*bas* and *enh*), the QR limit of 60 % is easily reached even in the harsh climates analyzed.
The building is close to being a zero-energy building on an annual basis at all locations investigated, as demonstrated by the energy matching chart (Luthander et al., 2015). The solid line in Fig. 12 connects all points where SCF is equal to LCF, implying that annual PV production is equal to annual load. A point above the bisector means that the annual PV generation is greater than the annual consumption of the building.

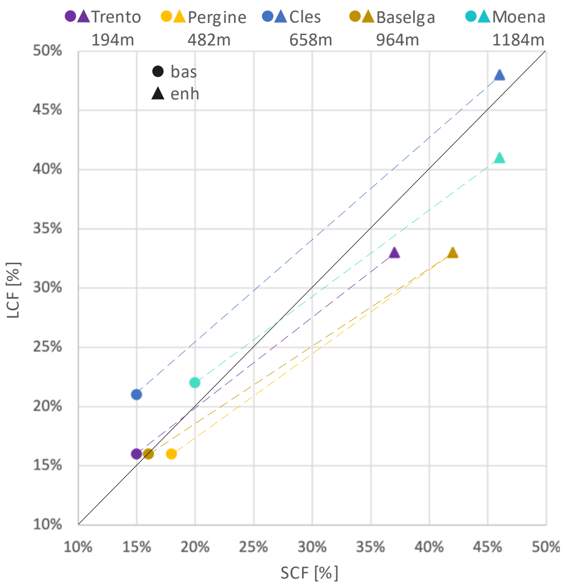

Fig. 12 – Comparison between bas (circle) and enh (triangle) through matching chart

The graph then shows how the control simultaneously increases SCF and LCF. However, there is a tendency for SCF to increase more than LCF, due to the slight increase in consumption. However, it should be emphasized how this is done by installing a cheap controller. A higher performance is achievable with (more expensive) batteries, which allow a better match of the building load to the solar availability.

4. Conclusions

The results show that 60 % renewable share is easily achieved in a new building, even in the mountainous areas analyzed.

If no control strategies aimed at maximizing self-consumption are employed, achieving a monthly QR of 60 % means an actual renewable share of about 13 % less, whereas, using an enhanced control strategy, the actual renewable share is about 6 % less than the monthly balance.

By closing the balance on a monthly basis, advanced control strategies are not rewarded. In fact, the pursuit of self-consumption often leads to an increase in energy demand, which, by closing the budget on a monthly basis, can lead to a reduction in the renewable share.

These controls, however, are beneficial in terms of reduced exchanges with the grid. In Trento, there is a 22.3 % increase in PV self-consumption and a 17.2 % increase in PV coverage of electricity consumption if the balance is closed on a minute or hourly basis. Taking all 5 municipalities into consideration, SCF rises by about 26 % and LCF by about 19 %.

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Nomenclature

Symbols

A	Surface (m^2)
$A_{Floor}L$	Gross surface (m^2)
$A_{Floor}N$	Net surface (m^2)
ASHP	Air-Source Heat Pump
BAS	Base control strategy
BS	Buffer Storage
ENH	Enhanced Control Strategy
HP	Heat Pump
LCF	Load Cover Factor
MF	Single-family
PV	Photovoltaic
QR	Quota of renewable primary energy
SC	Self-Consumption
SCF	Supply Cover Factor
T_{air}	Air-dry bulb temperature (°C)
T_{design}	Design temperature (°C)
TES	Thermal Energy Storage
U	Thermal transmittance ($Wm^{-2}K^{-1}$)
V	Volume (m^3)

Subscripts/Superscripts

ho.	Hour
mi.	Minute
mo.	Month
w,E-W	East and West-oriented windows
w,N	North-oriented windows
w,S	South-oriented windows

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