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Energy efficiency measures for buildings in Hebron city and their expected impacts in the distribution grid

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Abstract

The energy efficiency in buildings could represent one of the main opportunity, within a wide strategic scenario, to achieve energy independence of Palestine. In fact, the reduction of building energy demand due to the implementation of energy efficiency measures leads to a consequent decrease of the energy provision needs. For this reason an analysis of the potential reduction of the energy consumption in building need to be performed and a possible estimation of costs should be identified for defining a energy strategic plan of Palestine. This paper intends to highlight the potential of the energy efficiency measures in different building typologies of Hebron city in Palestine and their impact in the electrical distribution grid. The effectiveness of the different measures are estimated by means of software simulations and their optimal combination is also identified in order to maximize the reduction of energy demands. Finally, the variation of power losses in the distribution grid due to the retrofit action and a preliminary estimation of possible economic effort for the implementation of the proposed actions are also exposed.

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Keywords: Energy efficiency in Palestine; power losses in distribution grid; energy independence

1. Introduction

The increase of energy demand in Palestine due to population (i.e. +26% from 2007 to 2014) and urban growth [1] is recently forcing a technology transition from fossil fuels to Renewable Energy Sources (RES), like wind and solar, oriented also to energetic independence [2,3]. In fact, the energy provision in Palestinian territories is highly dependent from boundaries countries where, for example, the electricity needs are mainly covered through an import from Israel [1]. This holds particularly true in Hebron city where the present electricity needs are totally covered by the Israel Electric Corporation (IEC).

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Nomenclature

A_b	Surface area of a given reference building typology b in a city area (m^2)
$A_{tot,b}$	Total surface area of a given building typology b in a city area (m^2)
E_d	daily energy demand for a given subnet (kWh)
$E_{d,j}$	daily energy demand of j-th MV/LV transformer (kWh)
g	solar factor of glazed surfaces
$HLF(t)$	nomalized hourly load profile for a given subnet (p.u.)
$k(d)$	correction factor of the daily energy consumption in a given subnet
$P_b(t)$	load profile of a given reference building typology b (kW)
$P_{tot,b}(t)$	aggregated load profile for a given building typology b in a city area (kW)
$P_{sp,b}(t)$	load profile per unit of surface area of a given reference building typology b (kW/m^2)
$S_{n,j}$	rated power of j-th MV/LV transformer (kVA)
t_L	light transmittance of glazed surface
U	thermal transmittance (W/m^2K)

In this context, the energy independence of Hebron city can be potentially reached by the introduction of RES generation, as presented in [4], combined to energy storage systems, as discussed in [5], where the implementation of PV generation coupled with battery storage systems increases the exploitation of PV reducing also flux inversion (presently not allowed by IEC) at primary substation level of Hebron electric grid. However, more effectiveness condition can be obtained if RES generation is combined to a reduction of the existing energy needs through the implementation of energy efficiency measures in existing buildings, paving the way for urban regeneration and improvement of the quality of life [6].

Presently the most relevant energy consumption is covered by electricity which represents 35% of the whole energy demand, since space heating and cooling demands in Hebron buildings are covered by means of air-conditioner/heater (i.e. reversible heat pumps) with split units [7]. In particular, residential buildings need of 40% of the whole yearly electricity demand of the city, while industrial and commercial users need of 33% and 23%, respectively. Hence, deep energy retrofit actions need to be implemented in the whole Hebron buildings to reduce the overall electricity energy consumption of the city and to decrease the energy dependency from Israel. In fact, a significant reduction of the electricity demand can be expected through energy refurbishment of buildings as already observed in similar studies of Middle-East area where buildings suffer scarce thermal insulation [8–11], like in Hebron city. As a consequence, these energy efficiency measures have an impact also on the electrical distribution network (DN), which is presently slightly underloaded but reliable in Hebron [12], changing the energy requirements of final users [13–15]. Thus, this paper intends to identify at city scale the potential expected reduction on energy consumption due to energy retrofit in buildings and the consequent reduction of power losses in the DN.

The RENEP (Renewable Energy for Palestine) project, an initiative in the framework of the PMSP (Palestinian Municipality Support Program) [16] with the participations of SiTI, Ai Engineering s.r.l., the Municipality of Torino and the Metropolitan City of Torino, aims to study and evaluate the potential effects owing to the energy efficiency measures which could be implemented in different building typologies. Simulations of buildings energy behavior by means of IES<VE> software [17] were performed to evaluate and estimate the energy saving which potentially can be obtained by the implementation of the energy retrofit in buildings. Later, also the impact in the distribution grid through load-flow simulations and analysis were performed by means of NEPLAN [18]. The approach has been implemented by using real data collected on the fields, thanks to the collaboration with Hebron Municipality and HePCo (Hebron Power Company), the local utility responsible for the management of the electric grid.

2. Building Model

The Hebron urban environment is characterized by a great variety of building typologies which can be grouped into 4 main categories: commercial, educational, industrial and residential. For the scope of this work, some representative buildings have been chosen, becoming the pilot buildings on which the energy consumption analysis have been performed.

(a) (b) (c) (d)

Fig. 1. Reference buildings selected for energy modeling: a) residential, b) industrial, c) commercial, d) educational

The presence of these typologies has been assessed using the GIS database provided by the Hebron Municipality, in order to determine the total floor area of each type. This hypothesis allowed to extend the results obtained to all the buildings, returning fairly accurate estimates.

Initially, the profile of energy consumption has been assessed for the most representative buildings through a dynamic energy modeling using IES<VE> software, taking into account the outdoor temperature profile (see Figure 2). The energy modeling has been performed for each scenario, been focused on the evaluation of:

- Hourly Energy Demand, in the 3rd Wednesday of July and the 3rd Wednesday of December.
- Monthly Energy consumption
- Annual Energy consumption

In order to obtain an accurate energy assessment, it was necessary to consider the energy contributions of the different devices in the interior of the buildings and the constructive elements, specifically: building elements (transparent and opaque envelope), lighting and electrical devices, people occupancy, water heating, and heating/cooling appliances

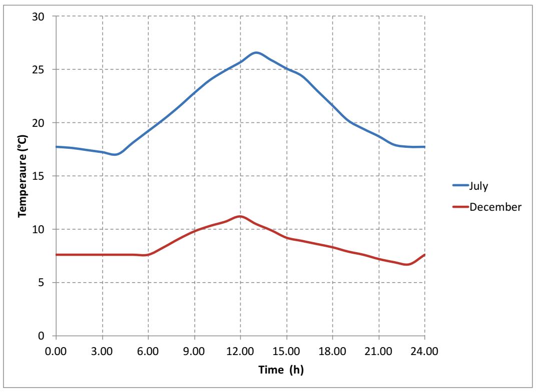


Fig. 2. Outdoor temperature profiles in Hebron.

Next, some improvement sets have been chosen for each type of building. Two kinds of improvements concern the envelope improvements (opaque and transparent), acting on the U factors, solar factor g and light transmittance t_L. The third kind of improvement regards the implementation of high efficiency HAVC systems, replacing the existing equipment. In this context, the "best scenario" for each typology of building has been identified, defining the set of suggested improvements on the basis of the energy modeling results.

Table 1. Performance of the reference buildings

Surface		Educational	Commercial	Industrial	Residential
Opaque	Roof	U = 1.25W/m^{2}K	U = 0.70W/m^{2}K	U = 1.20W/m^{2}K	U = 1.20W/m^{2}K
	Wall	U = 1.20W/m^{2}K	U = 0.50W/m^{2}K	U = 1.00W/m^{2}K	U = 1.00W/m^{2}K
Transparent	Glass	U = 4.50W/m^{2}K; t_L = 0.80; g = 0.84	U = 2.80W/m^{2}K; t_L = 0.50; g = 0.50	U = 2.80W/m^{2}K; t_L = 0.75; g = 0.80	U = 2.80W/m^{2}K; t_L = 0.75; g = 0.80

Finally, the energy modeling results have been extrapolated over the area, considering the buildings distribution. Every scenario is characterized only by a hourly electricity demand profile, since the presently energy consumption for space heating and cooling of the different end-user typologies is based on a electricity-driven scenario [7]. The profiles have been evaluated both in winter and summer condition.

Within the network analysis, the buildings play a key-role and affect the distribution of the power flows in the grid. Thus, for the distribution network analysis the new load profiles are an important input, providing information concerning the user-side of the smart grid.

3. Energy retrofit solutions in buildings

According to the modeling procedure described before, the improvement sets have been chosen for each building category following the indications pointed out in [19] where the integration between improvements of building envelop and installation of renewable energy sources (e.g. reversible heat pump) for space heating and cooling is suggested also from life-cycle point of view:

- TYPE 1 and TYPE 2; measures able to improve the opaque and the transparent envelope, acting on the U factors, solar factor g and light transmittance t_L.
- TYPE 3: installation of high efficiency air conditioning systems instead of the existing ones.

Table 2. Energy efficiency measures

Application	Type	Measure	Case	Improvements
Opaque Envelope	*TYPE 1*	Insulation upgrade	1a	-50% of U
		Insulation upgrade	1b	-75% of U
Glazed Envelope	*TYPE 2*	Glass Replacement	2a	-50% of U / -25% of g / -25% of t_L
		Film	2b	-50% of g / -50% of t_L
HVAC System	*TYPE 3*	Heat Pump Replacement	3a	COP from 3 to 3.7 EER from 2.8 to 3.5

Then, referring to the energy modeling results, the ”best scenario” for each building category has been identified, defining the set of suggested improvements.

Table 3. Optimal combination of different energy efficiency measures

Building Typology	**Best Combination**
Residential/Commercial	2b+3a+1a
School	3a+2b+1a
Industrial	1a+3a+2a

The set of suggested improvements varies for each destination of use (residential, commercial, etc) such as the priority of each improvement. A progressive diffusion of the improvements has been considered in the simulations, setting an annual penetration equal to the 5% of the applicable area for that improvements and assuming that the diffusion of each improvement doesn’t start in the same year. This assumption take into consideration the expected gap between the application of the most effective improvements and the less effective as per the priority list.

For example, let’s consider that for residential buildings the priority list of improvements results as follows:

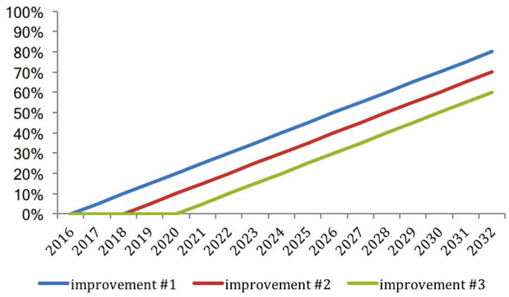


Fig. 3. Diffusion of the energy efficiency measures over the years

- reduction of the windows Solar Heat Gain Coefficient (SHGC) by the 50%,
- 50% reduction of the U-value of opaque envelopes,
- installation of new high efficient air-to-air heat pumps instead of the existing ones.

In the analysis, the improvement #1 start to be applied in 2017 to the 5% of residential buildings and in 2032 appears to be applied in the 80% of residential buildings. Similarly, the improvement #2 start to be applied in 2019 to the 5% of residential buildings and in 2032 appears to be applied in the 70% of residential buildings. Finally, the improvement #2 start to be applied in 2021 to the 5% of residential buildings and in 2032 appears to be applied in the 60% of residential buildings.

The load profiles evaluated through the energy modeling of each pilot building have been divided by the building's floor area, in order to obtain area-specific load profiles. Then, the results of the energy modeling have been spread over the city area, considering the building's distribution. Every condition is associated to a hourly load profile, describing the building's electricity demand. The profiles have been evaluated in winter and summer conditions, considering the improvements.

To reach this target, the following procedure has been applied. Initially, the pilot buildings have been modeled considering the actual conditions: this led to the baseline load profiles. Then, the models have been upgraded applying the most effective improvement, to obtain the load profiles characterizing those buildings where the improvement #1 is applied. Finally, the models have been improved again applying subsequently the improvement #2 and #3. In this way, the load profiles of buildings characterized by the presence of improvement #1 + #2 and improvement #1 + #2 + #3 have been obtained respectively. These procedure has been replicated for each type of building modeling the corresponding pilot site and using the corresponding list of improvement.

The specific load profiles obtained through the energy modeling of each scenario have been applied to the corresponding area to obtain the load profiles of the buildings under each substation. These profiles have been obtained per each year within per observation period considering the improvement's penetration.

4. Extension to urban context

The results obtained for a single unit of each building typology were spread over the whole buildings of the Hebron according to the GIS information of the building distribution in the city and the load profiles obtained through the simulations. The extension to the whole urban context of the electricity consumption estimated for each building typology is based on a two-step procedure. In the first step, the load profile of a building typology was converted in an average consumption per unit of surface area by dividing the load profile for the average surface area of a given unit of building typology, as follows:

$$P_{sp,b}(t) = \frac{P_b(t)}{A_b} \tag{1}$$

In the second step, an analysis on the buildings distribution over the whole city was performed through GIS tools. Since the impact of the energy retrofit on the grid needs to be evaluated, the building distribution is further subdivided

Table 4. Total occupied surfaces of different building typologies.

Subnet	Building Typology Residential (km^2)	Commercial (km^2)	Educational (km^2)	Industrial (km^2)
Duhdah Electric Substation (SS1)	0.813	0.219	0.087	0.073
Ras Electric Substation (SS2)	0.406	0.147	0.088	0.017
Fahs Electric Substation (SS3)	0.279	0.048	0.016	0.049
Harayek Electric Substation (SS4)	0.468	0.122	0.043	0.024
West Electric Substation (SS5)	0.654	0.172	0.081	0.034
Dusien Electric Substation (SS6)	0.522	0.106	0.069	0.019
Um Aldalieh Electric Substation (SS7)	0.615	0.151	0.092	0.120

according to the area where each substation of the present electric distribution grid feeds the end-users. The current electric distribution grid is formed by 7 primary substations capable to supply all the end-users, so 7 areas were identified in the city.

Table 4 summarize the information extrapolated by the GIS analysis regarding the surface area effectively used and occupied by the different building typologies. Finally, the average consumption profile of each building typology defined in Eq. 1 was multiplied by the corresponding real overall surface in each subnets area, as follows:

$$P_{tot,b}(t) = P_{sp,b}(t) \cdot A_{tot,b} \tag{2}$$

Thus, the aggregated load profiles estimated for each building typology were summed up in each subnets area in order to obtain the aggregated electricity demand of the whole buildings and evaluate the variation of the overall load profiles at primary substation level.

The real area considers the number of units already build in the city excluding all those not yet occupied. Nowadays, the average rate of unoccupied/unused buildings is close to 20-30% in most of the substation area considered in this paper.

For the sake of the simplicity, the implementation of the procedure exposed above, is based on the hypothesis that all the buildings of a given typology have the same load profile. Thus, the aggregated load profiles in each area does not consider the possible shifting of the load profiles of the same building typology due, for instance, to different energy behavior of the users.

To evaluate the global budget required to improve the buildings as described, the following hypothesis have been considered:

- the local costs for the installation can be considered 50% lower than the average European price (this indication has been derived from the tender procedure applied for the PV and Wind turbine purchased in the project)
- the buildings surfaces have been derived from the GIS database
- the progressive diffusion of the improvements has a linear behavior over the reference period.

According to the previously mentioned hypothesis, the estimated global budget for the buildings energy improvement could be close to 50 M€/year during the reference period. These interventions could lead to an expected energy saving close to the following values:

- 29% for the residential buildings,
- 6% for the commercial buildings,
- 9% for the schools,
- 3% for the industrial buildings.

Considering that the main part of the buildings in Hebron are residential, the improvement plan could lead to a substantial reduction of the urban energy consumptions.

5. Impact on local distribution network

The impact of the retrofit solutions in the local distribution network (DN) was evaluated considering two reference days with conventionally higher energy demand: the third Wednesday of December and the third Wednesday of July. Firstly, the present condition of the Hebron DN was simulated for both of reference days in the NEPLAN environment, which is a commercial software for power-flow analysis. In this way, the power losses along the DN was calculated for the current situation. Secondly, the power-flow analysis and the evaluation of the corresponding power losses was performed for both reference days considering the reduction of electricity demand due to the implementation of the proposed retrofit solutions. Finally, a comparison between the present and the future condition of the power-flows and power losses was performed to highlight the benefit related to the adoption of the energy retrofit actions in buildings.

The topology of the Hebron DN was implemented in NEPLAN environment by subdividing the whole grid in 7 subnets. Each of these subnets represents a portion of the DN supplied by one of the 7 primary substations presently used to feed all the end-users of the city. However, only 6 subnets were here considered due to the lack of information regarding the present condition of the subnet SS3 which refers to the old part of Hebron city.

Data and characteristics of the grid (i.e. lines length, kind of cable-lying, resistance and reactance of cables, cable ampacity, etc.) was supplied by the local utility HePCo, together with the present yearly electricity consumptions measured at primary substation level on hour basis. Table 5 summarizes the main electrical characteristics of the MV/LV transformers connected to the grid.

Table 5. Number of MV/LV transformers in the whole Hebron grid

	S_n									
Subnet	100 (kVA)	125 (kVA)	160 (kVA)	250 (kVA)	315 (kVA)	400 (kVA)	500 (kVA)	630 (kVA)	800 (kVA)	1000 (kVA)
SS1	7	-	10	24	3	32	7	26	4	6
SS2	2	1	3	10	-	18	1	14	11	3
SS4	5	-	4	9	1	18	2	9	-	1
SS5	1	-	9	18	1	21	1	22	2	5
SS6	-	-	3	3	-	5	-	19	6	3
SS7	1	-	5	14	-	6	-	11	1	1

5.1. Modeling of load profiles

The modeling of load profiles implemented in the NEPLAN environment combines the methodology proposed in [4] with the profiles obtained through the IES<VE> software in Section 2. In practice, the modeling of the present load profile is based on the measured electricity consumption at primary substation level, while the future load profile is based on the estimated electricity consumption identified by means of IES<VE> software.

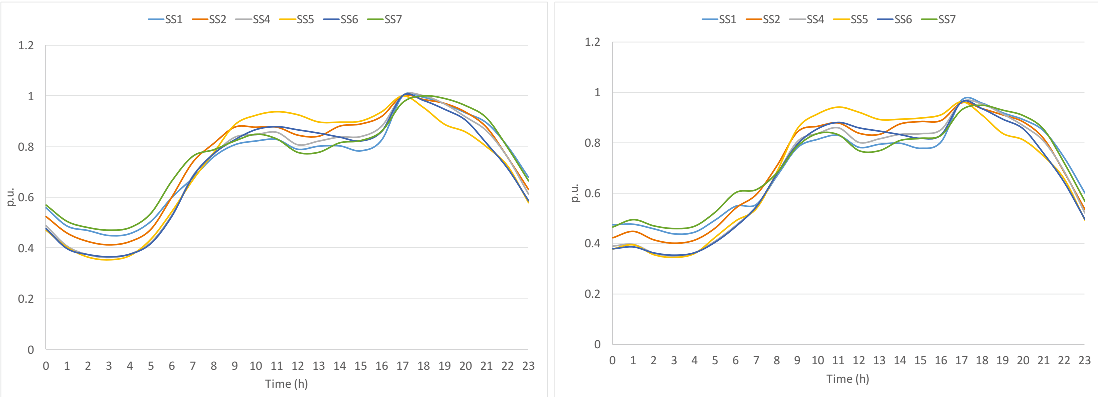
Under the assumption that the normalized end-user load profile is the same at each MV/LV substations of a given subnet, the measured and estimated electricity consumption at each HV/MV substation in the reference days, has been arranged to define an hourly average normalized load profile $HLF(t)$. Subsequently, the measured and estimated daily energy consumption at primary substation level are dispersed over each MV/LV transformer of a subnet according to its size and a correction factor k_d, as follows:

$$E_{d,j} = k_d \cdot S_{n,j} \cdot \sum_{t=1}^{24} HLF(t) \tag{3}$$

The correction factor k_d is introduced to ensure that the sum of the daily energy consumed in all MV/LV substations is equal to the daily energy measured ad primary substation level, so that k_d can be defined as follows:

$$k_d = \frac{E_d}{\sum_{j=1}^{N_{tr}} S_{n,j} \cdot \sum_{t=1}^{24} HLF(t)} \tag{4}$$

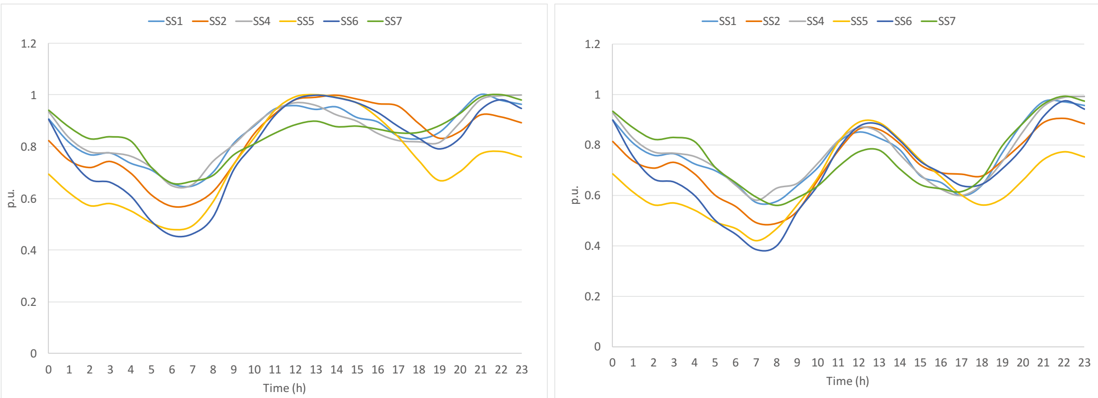
Thus, the normalized profile derived from the measured electricity consumption was used to evaluate the power-flow and the losses in the present condition of DN, while the power-flow and the losses in the future condition were calculated considering the estimated electricity consumption due to the energy efficiency measures in building.



(a) (b)

Fig. 4. Normalized daily load profiles at primary substation level for 3rd Wednesday of December: a) measured (present), b) estimated (future).

The reduction of the electricity demand can be highlighted by comparing Figure 4 and Figure 5 where the normalized load profile for the reference days in present and future condition are shown: the higher reduction can be observed in the third Wednesday of July.



(a) (b)

Fig. 5. Normalized daily load profiles at primary substation level for 3rd Wednesday of July: a) measured (present), b) estimated (future).

5.2. *Results of load-flow simulations*

The results of the simulation in NEPLAN environment of the present and future grid condition are summarized in Table 6 and in Table 7. In particular, Table 6 highlights the reduction of the daily electricity consumption due to the implementation of the proposed retrofit actions. The different energy saving obtained in each subnet are related to the different share of building typologies which are presently observed in the area where the subnet is located. The most relevant reduction can be observed in the third Wednesday of July where a general decrease higher than 10% could be potentially achieved in all the analyzed substations. A lower energy saving could be obtained instead in the third Wednesday of December, where the expected reductions could be close to 5%. Consequently, an overall energy saving of about 84MWh/day which corresponds a reduction of about 11.7% can be obtained in July, while an overall energy saving of 46MWh/day with a corresponding reduction of 5.4% can be observed in January.

Table 6. Reduction of the grid energy consumption expected for the reference days

Subnet	Total daily energy consumption 3rd Wednesday of July (MWh)		Reduction of daily energy consumption (%)	Total daily energy consumption 3rd Wednesday of December (MWh)		Reduction of daily energy consumption (%)
	Present (2016)	Future (2032)		Present (2016)	Future (2032)	
SS1	133.61	118.99	10.94	104.16	99.20	4.76
SS2	163.31	142.57	12.70	248.33	234.66	5.51
SS4	91.67	82.26	10.26	110.93	104.83	5.50
SS5	166.00	145.67	12.25	171.63	162.63	5.24
SS6	84.27	74.31	11.82	106.58	100.72	5.50
SS7	81.41	72.35	11.68	109.11	102.79	5.79

In this context, considering an estimated average electricity consumption for a residential end-user in Hebron close to 2.915MWh/year [1], the sum of the daily energy savings obtained in July and December could potentially cover the energy consumption of about 45 households for one year. These results also highlight how the implementation of the energy retrofit measures in buildings can lead to a reduced energy dependence of Hebron city. In fact, Hebron presently covers its local electricity demand only by means of the energy supplied by Israeli transmission grid, since no electricity self-generation is acted in West Bank region of Palestine.

Table 7 shows instead the reduction of the power losses in the DN due to the implementation of the proposed retrofit actions. According to the results observed for the reduction of electricity consumption, also a reduction of energy losses could be potentially obtained by means of the renovation actions. In particular, the most effectiveness reduction can be obtained in July where the power losses could be reduced from 3.63% of SS1 and SS4 to 19.73% of SS6, increasing the efficiency of the DN in Hebron. As a consequence, the sum of daily reduction of power losses for all the subnets in the third Wednesday of July can potentially reduce the CO_2 emissions of about 0.63t/day, while a reduction of 0.47t/day of CO_2 emission can be expected in the third Wednesday of December, adopting the CO_2 emission factor defined in [20].

Table 7. Reduction of the power losses expected in the distribution grid for the reference days

Subnet	Total daily network losses 3rd Wednesday of July (MWh)		Reduction of daily network losses (%)	Total daily network losses 3rd Wednesday of December (MWh)		Reduction of daily network losses (%)
	Present (2016)	Future (2032)		Present (2016)	Future (2032)	
SS1	3.281	3.162	3.63	3.066	3.033	1.08
SS2	2.684	2.422	9.78	4.275	3.999	6.46
SS4	1.520	1.427	3.63	1.807	1.728	1.08
SS5	2.739	2.529	7.68	2.839	2.751	3.11
SS6	0.332	0.268	19.73	0.524	0.477	8.99
SS7	1.390	1.285	7.56	1.875	1.764	5.93

6. Conclusion

The implementation of the energy efficiency measures in the different buildings typology of Hebron city in Palestine, which suffer of scarce thermal insulation and inefficient heating and cooling system, has been explored in this paper. The results highlights that energy retrofit actions are substantially capable to reduce the energy consumption for the different end-user typologies, which also correspond a reduction of their energy bills. In particular, a stronger reduction is expected for household (i.e. around 29% with respect to its present energy demand) which also represents the largest end-user typology in Hebron.

Consequently, since Hebron is fully energy dependent from Israel, a benefit can be also potentially obtained in terms of reduced costs for the energy provision of the whole city. Meanwhile, electric distribution grid benefits of reduced power losses and of an increased efficiency which also corresponds to a reduced greenhouse gases emissions.

In this context, no upgrade of the DN need to be implemented, since the present underloaded condition of the grid was further reinforced if the reduction of electricity consumption was acted.

However, the aforementioned retrofit actions in the buildings requires a financial and economic effort if the expected results need to be achieved in the supposed time horizon. For this reason, economic support actions have to be identified and implemented. In this context the following evidences should be considered: the cost of energy in Hebron is relatively high (as it's compared to an European value) while the expected investment cost for the improvements is lower than the European average (as demonstrated within the tender procedure for the PV and wind turbine purchasing in the project).

Thus, the energy improvement of buildings seems to be an effective initiative, self-sustainable under the economical point of view. The study emphasized that there is still a lack in the legal framework concerning the energy efficiency in buildings. Nevertheless, the results achieved through the simulation at urban level and the identification of the optimal improvement sets could became the starting point for the definition of an Energy Plan in the city of Hebron.

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