EXPLORING THE IMPACT OF HEAT PUMP-BASED DWELLING DESIGN ON THE LOW-VOLTAGE DISTRIBUTION GRID

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ABSTRACT

As a result of the requirements for energy efficiency and the related vast deployment of PV and heat pump systems, a rise in the electrical loads introduced on the low voltage distribution grid can be expected. The latter can lead to possible violations of grid technical constraints which will require adjustable measures to be taken. This study investigates the impact of the building design on several grid restriction criteria. A thorough sensitivity analysis is performed based on detailed simulation of two Belgian residential neighbourhoods, where the building parameters are varied in a Monte Carlo simulation. The analysis shows that building parameters aggregated for the neighbourhood show stronger correlations than average ones, and can be confidently linked to the grid performance indicators, with the potential to be used in meta-modelling of neighbourhoods. However, sampling efficiency and input correlation issues are found to require further attention. Such a meta-model, aiming at examining the influence of grid constraints on the efficiency of building energy policies, will be implemented in future work.

INTRODUCTION

On the trajectory towards a low-carbon energy society, European regulations for energy efficiency enforce the transition to nearly zero-energy buildings, and renewable heating and cooling. As a result, national energy policies propose a wide deployment of heat pumps (HP) and photovoltaic systems (PV) in the building sector.

The introduction of electric heat pump based systems in the residential Belgian building stock as a substitute of the dominant gas boilers will generate a drastic change in the electrical grid loads. Simultaneously, distributed solar energy generation is introduced as a variable, non-dispatchable load which is mostly abundant at times of low demand in central Europe. Given the currently limited exploitation of energy storage systems, these loads are imposed on the existent low-voltage distribution grid. Possible outcomes of this are violations of technical constraints and resulting curtailment of renewable electricity generation. Such problems, which are particularly important in cases of high HP and PV penetration rates, need to be tackled by feeder reinforcement, adapted dwelling design or active demand response. As such, local grid restrictions can affect the effectiveness of a building energy efficiency policy and implicate externalised costs for the distribution system operator.

Within this context, the presented work aims at identifying the most influential building neighbourhood parameters with regard to their impact on several key performance indicators characterizing the low-voltage distribution grid. In contrast to earlier work, which focuses on the impact of feeder topology and HP and PV penetration rates (Baetens et al., 2012), special attention is given to building properties which (in-)directly affect the overall energy demand, the peak demand and the design load of heat pumps, and thus the resulting overall exchange of energy with the grid, e.g. the geometry and insulation level. As such, further study of the interdependency of building efficiency measures on electrical grid constraints will be facilitated.

To serve this purpose, a Monte Carlo method is applied to district energy simulations in the IDEAS district simulation environment considering the main parameters of two typical Belgian feeder configurations, i.e. an urban and a rural residential neighbourhood. These neighbourhoods are intended to represent the housing stock of the near future, where (i) new energy efficient buildings coexist with older less performing ones, and (ii) heat pump and photovoltaic systems have gained more ground reaching high implementation rates, as premised by the European Heat Pump Association, the European Insulation Manufacturers Association and the Buildings Performance Institute Europe (Bettgenhäuser et al., 2013, 2014). The studied neighbourhoods are purely residential; non-residential or large multifamily buildings are not taken into account as they are rarely connected to the same distribution grid. The impact of the additional electrical loads from the heat pumps and PV systems on the low-voltage grid constitutes the core of this research, and the electrical demand for space heating and domestic hot water are therefore simulated dynamically with the use of IDEAS. The simulation results are used to detect distribution grid weaknesses, evaluate the correlation with input parameters, and assess the importance of different neighbourhood characteristics.

METHODOLOGY

In this section the methodology adopted to achieve the above-mentioned objective is presented. An overview is shown in the diagram of Figure 1. Several steps are
taken in order to set up the Monte Carlo loop, perform the simulations and analyse the results. First, a collection of buildings to represent the examined building stock is created, along with various scenarios for the feeder configurations. Next, all neighbourhood cases are generated based on the different scenarios and buildings sampled from the available collection. Then, for each case representative neighbourhood parameters are selected and calculated. Furthermore, grid performance indicators are defined and deduced from the neighbourhood simulations. In a final step, the relationship between the neighbourhood parameters and the performance indicators is examined. The following subsections will describe in detail steps 1 to 5. Subsequently, the ‘Model description’ Section describes the simulation models and assumptions, whereas the analysis is presented in the ‘Results’ Section.

**Step 1: Building definition**

In order to study the impact of building properties on the distribution grid, a parametrization of the buildings is necessary. Therefore, the first step consists of creating a collection of buildings from which the neighbourhood cases are populated. The buildings are parametrized primarily based on their geometrical and thermal characteristics, because these influence the electricity demand of the building by altering the thermal energy demand. Additionally, different heat production systems are considered. Last, the nominal installed PV capacity is also introduced as a parameter. The influence of occupant behaviour is taken into account by means of stochastic profiles, but is not treated as a parameter. All building parameters are summarized in the top part of Table 1.

To each of the parameters, an arbitrary probability distribution is allocated based on common practice and current regulations in Belgium (Table 1), with the purpose to obtain realistic ranges for the future building stock of the country. The distribution range for the nominal PV capacity is limited by the available roof area or to 5 kVA, which is the maximum allowed capacity for a single phase connection in Belgium (Synergrow, 2009).

A total of 100 parameter combinations are sampled from the probability distributions using a ‘maximin Latin Hypercube sampling’ (LHS) scheme, in order to create a large collection of buildings to populate the feeders from. As described by Janssen (2013), such a sampling allows to fill the multi-dimensional probability space more efficiently with less samples. Correlations between the various inputs have not been taken into account.

As required for the IDEAS simulations, also 100 different stochastic user behaviour profiles are generated from the 5tr08e package, as described in the ‘Model description’ Section, and are randomly coupled one-to-one to the parameter combinations. To maintain the parameter distributions when sampling buildings in a neighbourhood, three building variants are created for each of the 100 combinations, namely one detached (D), one semi-detached (S) and one terraced (T) dwelling. The small differences between the building variants stem from the different geometry, since all follow the simple rules shown in Figure 3, starting from a given volume.

Each building case is simulated with the Modelica IDEAS Library using the models described in the next section, resulting in 300 (3x100) residential electricity demand profiles with a time resolution of 15 min. From this collection of profiles the neighbourhood models draw their inputs.

**Step 2: Neighbourhood scenarios**

In a second step the various feeder scenarios are created. Two ‘typical’ Belgian feeder configurations are studied, representing a rural and an urban feeder, as shown in Figure 2. These feeders are defined earlier in (Baetens, 2015) based on the Flemish Sizeable Reference Record and Endis’ Low-voltage Chart. The cable lengths, number of houses and building types are kept fixed for all studied cases. The cable type, the implementation rates for HP and PV systems, and the feeder orientation (determining the PV orientation in the urban feeder) are considered as scenario parameters. This is done because, although they are independent of the building stock characteristics of the neighbourhood, they might significantly influence the distribution grid performance. Twenty scenarios are generated for each feeder to account for the scenario parameters displayed in the bottom part of Table 1. The number of scenarios is limited due to shortage of computational resources, considering the large simulation time required for the neighbourhood
simulations. The sampling of the parameters is once more effectuated by means of a maximin LHS.

Table 1 Overview of the varied buildings (upper part) and the neighbourhoods (lower part) input parameters and their considered distributions.

| Parameter                      | Distribution
|-------------------------------|----------------
| **Building**                  |                |
| Volume, m³                    | Uni (200, 600) |
| window-to-wall ratio (wwr), - | Uni (0.15, 0.45)|
| Glazing type, (-, W/m²K)      | 2p (g=0.755, U=1.4) |
| (U_frame = 0.8 W/m²K)         | 2pAr (g=0.589, U=1.1) |
|                               | 2pKr (g=0.598, U=1.0) |
|                               | 3pKr (g=0.407, U=0.7) |
| U-value external walls, W/m²K | Uni (0.1, 0.6) |
| U-value roof, W/m²K           | Uni (0.1, 0.6) |
| U-value ground floor, W/m²K   | Uni (0.1, 0.6) |
| Airtightness (tna), k³         | Uni (0.4, 12.0) |
| Ventilation recup. efficiency, - | No recuperation / 0.80 |
| Orientation (0° ± S), °        | [-90, 90], step 10° |
| Heating system                | Air coupled HP |
|                               | Ground coupled HP |
|                               | Air coupled HP + DHW |
|                               | Ground coupled HP + DHW |
| PV nominal power, W           | Uni (3000, 5000) |
| **Neighbourhood**             |                |
| Cable type                    | EXAVB 4 x 70mm²|
| EXAVB 4 x 95mm²               | EXAVB 4 x 150mm²|
| HP implementation rate, -     | 0.2 / 0.4 / 0.6 |
| PV implementation rate, -     | 0.4 / 0.6 / 0.8 |
| Feeder ori. (0° ± S), ° (urban)| [-40, 40], step 10° |

1 Uni(a,b) denotes a uniform distribution between a and b. For discrete uniform distributions, the possible values or the range and step are given.  
2 Value referring to the ‘steady-state’ U-value of a slab on ground.

Step 3: Neighbourhood definition

Next, the neighbourhood cases are created using the results of the previous steps. Here, ten different building combinations are generated for each neighbourhood scenario. For each building combination, buildings are sampled from the collection created in Step 1 and assigned to each of the neighbourhood’s houses. The neighbourhood case is created by first sampling a building ID from the building collection for each of the neighbourhood’s houses. The sampling method is further explained in the dedicated paragraph bellow. Depending on the building type of each house (i.e. D, S or T), the profile is taken for the sampled building ID from the appropriate variant. Then, based on the HP and PV implementation rates, the number of houses with HP or PV systems is defined. The heat pumps are randomly attributed to the neighbourhood houses, and the earlier-on simulated electricity demand profiles are used in the neighbourhood simulations for the HP-based dwellings. The dwellings without HP systems are only represented by the occupant receptacle load profiles. For the urban feeder, the houses with PV systems are also randomly chosen. The PV panel orientation is assumed to be the same for all houses and equal to the street orientation defined as a parameter of the neighbourhood; the orientation of each building may still vary, and shouldn’t be confused with it. For the rural feeder, each house maintains its orientation also regarding the PV panels, and in this case the dwellings with roof orientation closer to South are chosen to have a PV system. The nominal powers sampled in Step 1 are used for all buildings with PV for both feeders.

Note on sampling. In a first approach, sampling is done by randomly selecting without replacement building IDs from the entire range [1-100], resulting in a set of 200 simulations per feeder configuration. However, this sampling method leads to a narrow range of average overall neighbourhood properties (see definition of neighbourhood properties in next subsection). In an attempt to widen the range of the resulting neighbourhood parameters in the sample set and to have a better estimation of their impact, two additional sets of simulations have been initiated for each feeder configuration.

The two new sets are designed as higher (HQ) and lower thermal quality (LQ) cases compared to the original set, i.e. they have an average thermal design load of 7.3 and 13.1 kW respectively in comparison to the 10.2 kW of the original set. The feeder scenarios and overall process of constructing them remains the same; only the sampling of buildings differs. In this case, the buildings collection is sorted based on the design heat load of the buildings (see next subsection), separately for each variant (D,S,T). This parameter has been shown to have the largest impact on the results and is therefore chosen for this purpose. The neighbourhoods are then populated with random selection from the lower or upper part of the sorted collection for each set respectively (rather than from the entire range). Since each new set requires 200 simulations as well, 600 simulations are performed in total for each feeder configuration (urban/rural). The analysis that follows in the ‘Results’ Section makes use of all 3 sets per feeder and combinations of them to highlight the importance of the sampling method.

Step 4: Neighbourhood parameters

The last step before the analysis, and parallel to the neighbourhood simulation, consists of defining the ‘neighbourhood parameters’ based on the scenario neighbourhood parameters and the individual building properties. These are the parameters that will be used for the analysis and therefore need to represent accurately the properties of the entire neighbourhood. The selection and computation of representative neighbourhood parameters is not a straightforward process, therefore it is tried in this paper to compare
different approaches. To this end, both average and aggregated values are examined. The basis for their calculation varies depending on the nature of the parameter. That is, building properties that influence the heat demand are only considered for buildings equipped with a HP system; building parameters that influence the PV production are only considered for buildings with a PV system. The latter is justified because the nominal power of the PV system is randomly assigned to the buildings and is therefore not linked to their energy demand. This would not be the case if a net zero-energy balance was aimed for. The chosen parameters are shown in Table 2, together with the method used to calculate them.

Table 2 Overview of the considered average neighbourhood parameters and the calculation method used for their definition.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol, Units Calculation method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable type</td>
<td>-</td>
</tr>
<tr>
<td>HP impl. rate</td>
<td>-</td>
</tr>
<tr>
<td>PV impl. rate</td>
<td>-</td>
</tr>
<tr>
<td>HP el. demand</td>
<td>$E_{HP} &amp; \Sigma E_{HP}, kWh$ avg HP (^1) &amp; sum HP (^2)</td>
</tr>
<tr>
<td>Design heat load</td>
<td>$Q_{des} &amp; \Sigma Q_{des}, kW$ avg HP &amp; sum HP</td>
</tr>
<tr>
<td>Volume</td>
<td>$V_{tot} &amp; \Sigma V_{tot}, m^3$ avg HP &amp; &amp; sum HP</td>
</tr>
<tr>
<td>UA-value</td>
<td>$q_A &amp; \Sigma q_A, W/mK$ avg HP &amp; sum HP</td>
</tr>
<tr>
<td>gA-value</td>
<td>$g_A &amp; \Sigma g_A, m$ avg HP &amp; sum HP</td>
</tr>
<tr>
<td>n50</td>
<td>$\pi_{50}, h^{-1}$ avg HP</td>
</tr>
<tr>
<td>wwr</td>
<td>$\pi_{wwr}$ - avg HP</td>
</tr>
<tr>
<td>avg U-value</td>
<td>$U_{avg}, W/m^2K$ avg HP</td>
</tr>
<tr>
<td>Building ori.</td>
<td>$\pi_{ori}$ - avg HP</td>
</tr>
<tr>
<td>SPF</td>
<td>$\pi_{SPF}$ - avg HP</td>
</tr>
<tr>
<td>PV ori.</td>
<td>$\pi_{PV}$ - avg PV (^1)</td>
</tr>
<tr>
<td>PV nom. power</td>
<td>$P_{nom, PV} &amp; \Sigma P_{nom, PV}, W$ avg PV &amp; sum PV (^2)</td>
</tr>
</tbody>
</table>

\(^1\) Average among buildings equipped with a HP / PV.
\(^2\) Sum over buildings equipped with a HP / PV.

Regarding the neighbourhood parameters used for the analysis we will additionally state that:

- The ‘HP electricity demand’ includes only the annual demand of the heat pump for space heating and domestic hot water production.
- The ‘design heat load’ $Q_{des}$ is calculated based on the European Std EN 12831 (2003).
- The ‘average U-value’ is the area-weighted average among all exterior surfaces of a building, while the ‘UA-value’ and the ‘gA-value’ are the sum over all exterior surfaces or total glazed area respectively.
- The ‘Seasonal Performance Factor’ (SPF) of the heat pump is calculated as the annual heat energy output over the annual electricity input.

Step 5: Grid performance indicators

The impact of different building properties on the distribution grid is evaluated in this work in terms of energetic efficiency and technical restrictions that may lead to grid maintenance costs, i.e. grid constraints regarding transformer loading, cable loading, voltage deviations and voltage unbalance problems.

To this end, the following set of indicators is defined: the minimum and maximum observed nodal voltages among all phases $(V_{min}, V_{max})$, the peak transformer load $P_{tra}$, the annual ohmic losses of the entire distribution network $E_{Q}$, and the characteristic daily voltage peak deviation $V_{rms}$. The latter is used to describe the voltage profile in the low-voltage distribution grid and is defined as the root mean square value of all daily maximum peak deviations:

$$V_{rms} = \sqrt{\frac{1}{n_d} \sum_{d=1}^{n_d} \sum_{k \in K_d} |V_{\phi,n} - V_{nom}|^2}$$

where $V_{nom}$ is the nominal grid voltage (here 230V), $V_{\phi,k}$ the voltage at the connection phase $\phi$ on time-step $k$, $n_d$ the number of days in the evaluation period and $K_d$ the set of time-steps in day $d$. Additionally, the annual curtailed PV generation $E_{cur}$ is evaluated.

MODEL DESCRIPTION

As briefly explained in the above section, the electrical energy demand has been simulated in advance for each building, using the building and system models, and the occupant profiles. Then, the resulting demand profiles are applied to the electrical network model. There, also the PV generation is introduced, accompanied by its control which allows curtailment. It must be noted that feedback to the thermal building model is not possible with this modelling approach. A simultaneous simulation of all model parts is possible, but increases dramatically the calculation time. Detailed presentation of the models is given below.

All models are simulated in the Modelica environment and are constructed using the IDEAS Library, as presented earlier by Baetens et al. (2012).
latter is publicly available at https://github.com/open-ideas/IDEAS. The simulations are all carried out for the typical moderate climate of Uccle (Belgium). Daylight saving time is taken into account and irradiation data with a time resolution of 1 min is obtained by Meteonorm v6.1 for the same location, all based on the period 1981-2000 (Meteotest, 2010).

Building model.

One general building model has been implemented, which has as parameters the ones determined in Table 1. The building geometry is defined based on the given volume and window-to-wall ratio, the type of building (D, S or T) and the basic geometrical rules shown in Figure 3. The building model has two thermal zones: the day-zone (e.g. living area, kitchen) and the night-zone (e.g. bedrooms, corridors). The envelope elements are designed as ‘typical’ Belgian constructions, as proposed by Cxy et al. (2011), but with insulation layers varying based on the desired U-value. The internal gains, read from the relevant occupant profile, are distributed 70% to the day-zone and 30% to the night-zone. All dwellings are equipped with mechanically balanced ventilation with an air change rate of 1.2 h⁻¹ and an optional recovery efficiency of 0.80.

Heating system model.

As stated earlier, four different systems are considered: either an air-coupled or a ground-coupled heat pump, to provide for space heating only, or additionally for domestic hot water (with the use of a storage tank).

The modulating heat pump is connected to low-temperature radiators in each thermal zone and the nominal powers of the heat pump and radiators are equal to the previously defined design heat load Q_{des}. The heat pump model is based on interpolation in a performance map retrieved from manufacturer data, which defines the heating power and electricity use as a function of the condenser outlet temperature, the evaporator temperature and the modulation (which goes down to 30 percent). The coefficient of performance based on manufacturer data is 3.17 at 2/35°C test conditions (i.e. evaporator/water temperature) and 2.44 at 2/45°C test conditions for full load operation. The heat pump is controlled based on the measured operative indoor temperature for space heating and the top temperature of the storage tank of 200 litres for the hot water production. The supply temperature setpoints of the heat pump are based on a heating curve for space heating, i.e. 55°C at an outdoor temperature of -8°C and 20°C at an outdoor temperature of 15°C, and 60°C for domestic hot water.

A heating season from 15 September till 15 May is considered, in accordance with common practice in Belgium.

Occupancy model.

Stochastic residential occupant behaviour profiles are generated for each dwelling with the Python StROBe Package as presented by Baetens and Saelens (2015). These include 10-minute profiles for the space heating setpoints for the day- and nightzone, and 1-minute profiles for the receptacle plug loads, hot water withdrawal and internal heat gains. All the above are used as input for the IDEAS simulations.

Building electrical model.

The nodal voltage of all appliances is set equal to the voltage of the building-to-feeder connection, and all electrical loads of the appliances are seen as active loads. Regarding the PV system, all solar panels are rated in Table 1.

To avoid excessive feeder voltages, the PV system inverter is disconnected when the voltage at the dwelling-feeder interface reaches a predefined voltage limit. Curtailing is applied because the distribution system operator currently does not allow the distributed sources to provide voltage control of the distribution grid, e.g. by reactive power control. This limit is set to a 10 percent increase of the nominal feeder voltage, or 253 V according to national regulations on AREI Art.235, the Belgian General Regulations for Electrical Installations (and Labour Protection). The inverter control is given a minimal off-time of 5 min before trying to switch on again after voltage disturbances.

Electrical network model.

The modelled residential neighbourhoods are typical radial feeders with a nominal voltage of 230/400 V wye connection. The simulations are performed using a three-phase representation of the electricity distribution feeder with asymmetrical loads and are based on a power flow analysis determining nodal voltages and line currents with the quasi-stationary method ΔV(t) = (R + jX)I(t).
the above observation clearly demonstrates that the occurring voltage fluctuations, expressed here as high $V_{\phi}^{\text{rms}}$, are the result of too low voltage rather than too high, and thus heat pump dominated.

**Parameter sensitivity.**

As the main goal of this paper is to investigate the influence of building characteristics on the above-mentioned distribution grid performance indicators, an in depth analysis of their correlations is performed. Spearman’s rank correlations are calculated for all different simulation sets (i.e. the HQ, LQ and original set) and their combinations, for the entire set or by scenario parameter, and for urban and rural feeders independently. This allows to have a better understanding of the real impact of the parameters, taking into account the influence of the sample set and the scenario. Rank correlations are chosen instead of a Pearson’s correlation since non linearity exist between the inputs and outputs of the models.

In Figure 5 the resulting correlation coefficients for all neighbourhood parameters are shown, for the ohmic line losses, the transformer peak load and characteristic voltage deviation. The first three depicted parameters are the scenario parameters and are calculated for the entire set each time, for rural and urban feeders separately. The remaining parameters are plotted per cable type, because it is the scenario parameter that influences the results the most and reduces the apparent importance of the building parameters when included as a parameter in the analysis. Furthermore, also the HP implementation rate has a great impact on the transformer peak load and the grid losses, represented by coefficients in average around 0.9 and 0.55 respectively. One can see the dominance of these two parameters on the box and scatter plots of Figure 6, as represented by the visual clustering of cases. This figure confirms the need for a multi-layer analysis where the above stated correlations are handled by means of exogenous scenario parameters. On the contrary, the PV implementation rate and total installed PV capacity only have a moderate impact on the maximum voltages ($\rho \approx 0.35$) and do not influence the other indicators. This is due to the limited nominal capacities of the considered PV systems. Additionally, the PV orientation and average PV nominal power are both found non significant for all indicators.

Concerning the building properties, the averaged parameters either have both low and not significant (i.e. when $p>0.05$) correlation coefficients, such as parameters [4-8] in Figure 5, or have considerably variable ones, such as parameters [10-15]; both situations don’t allow any confident conclusion to be drawn. For the latter parameters an explanation might be sought in the fact that they are dominated by implementation rates, and are thus preferably combined in aggregated parameters. Additionally, it can be argued that among different sets the resulting probability distribution of

**RESULTS**

In this section the simulation results are presented and analysed in order to bring forward grid performance issues and their correlation with the neighbourhood properties. Figure 4 summarizes the results from all simulations and provides a basis for a comparison between the two feeder configurations. Each boxplot is the result of 600 neighbourhood simulations. In general, one can deduce from this figure that rural feeders suffer more from voltage problems and energy losses, which can be attributed to the longer distances between consumers.

**Voltage constraints.**

At first, one can clearly see that the maximum allowed voltage $V_{\phi_{\text{max}}} \leq 1.1V_0$ equal to 253 V is only exceeded for two of the 1200 neighbourhood simulations. These represent rural feeders with the weakest cable and also the only cases where photovoltaic energy curtailment has been observed; though the amount of curtailed energy is not noteworthy, i.e. below 33 kWh/y. Despite the quite high PV implementation levels (i.e. up to 80%), the limited installed capacity of up to 5 kVA per household is found to be insufficient to cause over-voltage conditions. For this reason, the indicator $E_{\text{curt}}$ has been excluded from further analysis.

On the contrary, the soft lower limit $V_{\phi_{\text{min}}} \geq 0.9V_0$ equal to 207 V is in many cases violated, indicating that low voltage problems will be of greater importance in the near future, assuming the penetration rates for PV and HP of this study. Although such low voltage would not be allowed in reality as it may cause malfunctioning or possible damage of appliances, the possible switching off of the heat pumps due to this low voltage is not implemented in our simulation model. As a consequence, also potential thermal discomfort for the occupants due to this cannot be examined in this work. Nonetheless,
these average parameters differ significantly as a result of the sampling scheme, thus creating these discrepancies. For this reason, further study of the effect of the sampling method and ranges on the results will be studied in future work.

On the other hand and as stated earlier, more clear is the influence of the aggregated neighbourhood parameters (16-20) because they incorporate the different HP implementation rates in their calculation. For those, a constant high correlation is found for a specific cable type regardless of the simulation set, with coefficients ranging from 0.7 to 0.9 on average. Concerning the transformer peak load, independently of the cable, which has no impact, these parameters are of main importance as can be also seen on Figure 6. The observation of high correlations is valid equally for urban and rural feeders, and also for weak as well as strong cables.

Discussion

This performed sensitivity study shows that the main grid performance indicators can be confidently linked to thermal building properties through several neighbourhood parameters, namely the aggregated volume, UA-value and gA-value; the nominal total heat load Qdes and the annual heat pump electrical demand. For this reason these parameters can be considered as good candidates to be used in meta-modelling of the resulting loads, the occurring voltage fluctuations and the ohmic energy losses in low voltage distribution grids. Such an approach will be taken in future work in an attempt to evaluate the potential impact of grid constraints on the energetic or monetary efficiency of building related energy policies. However, in a procedure like that, occurring or existing correlations between the considered building parameters as shown in Figure 7, cannot be overlooked and methods suitable for correlated inputs must be used (Tian et al., 2015).

CONCLUSIONS

In this work the influence of building characteristics on the low voltage distribution grid has been studied for two ‘typical’ Belgian neighbourhoods. The analysis focused on the voltage profile, transformer peak load and distribution losses, as well as on the PV generation curtailment. A large set of neighbourhood simulations has been carried out using the IDEAS Modelica library, which served as input for the analysis. The results highlighted the distribution grid weaknesses in regard to accommodating increasing amounts of heat pump and PV loads. In particular, it has been shown that for the studied feeder cases practically no overvoltage conditions occur, but undervoltage is the main issue that should be accounted for. Regarding the influence of building properties, it has been found that several neighbourhood parameters show strong correlation with the transformer peak load, grid energy losses and to a lesser extend with the voltage deviations. More specifically, the aggregated volume, UA-value and gA-value, the nominal to-
Figure 6 Influence of several neighbourhood parameters on the grid losses $E_\Omega$, transformer peak load $P_{tra}$, and characteristic voltage deviation $V_{\phi rms}$. All simulation cases are plotted for the rural feeder. The different colors of the scatter plots denote a different cable type.

Figure 7 Correlation between the total neighbourhood design heat load and the average $U$-value, average and total volume.

tal heat load and the annual electrical demand for heating of the buildings with a heat pump demonstrated high correlations with the outputs. This influence was noticeable especially within neighbourhoods with the same cable type. The findings of this work further suggest that the above-mentioned neighbourhood parameters could be effectively used as inputs to a ‘neighbourhood meta-model’. However, sampling efficiency and correlations between building parameters were found to be issues that require additional attention. Taking into account these observations, a meta-model aiming at examining the influence of grid constraints on the efficiency of building energy policies will be part of related future work.

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