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SENSITIVITY ANALYSIS OF HEAT LOSSES IN DISTRIBUTION SYSTEMS: IMPACT OF DIFFERENT BUILDINGS TYPOLOGIES

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ABSTRACT

This paper focuses on the sensitivity of heat losses in collective heat distribution systems using a simplified calculation method. The methodology considers several parameters influencing the performance of heat distribution systems. Hence, the thermal properties of the heat exchanger in the dwelling heating substation and the return temperature of sanitary hot water are considered. In addition, the recirculation control strategy, the length of service branch which is included or not in the recirculation as well as, the share in a building of dwelling heating substation with similar characteristic and control strategy are also taken into account. The present study assess the impacts of some potential variations in the input variables, on the conclusions of the methodology. A comparison of the sensitivity of heat losses in the heating distribution system between four different buildings typologies, i.e. with 13, 24, 25 and 49 apartments, is provided. In order to identify the influence of building typology and pipe layout in the heat losses calculation, for the four cases the sensitivity analysis was carried out. A study was conducted through sensitivity analysis by means of an experimental design, consisting of the combinations of parameters which were varied from the levels at which they were set. Results shows how sensitive the solution is in the face of different parameter values as well as under what circumstances the solution would change. The suitability of the improved method which allow more flexibility to consider different pipe layout characteristic within a heating distribution system was demonstrated.

KEY WORDS: Dwelling heating substations, Heat distribution systems assessment, Sensitivity analysis

ANÁLISIS DE SENSIBILIDAD DE LAS PÉRDIDAS DE CALOR EN SISTEMAS DE DISTRIBUCIÓN: IMPACTO DE DIFERENTES TIPOLOGÍAS DE EDIFICIOS

RESUMEN

Este estudio se centra en la sensibilidad de las pérdidas de calor en sistemas de distribución de calor. La metodología considera varios parámetros de diseño que influyen en el rendimiento de estos sistemas. Se consideran las propiedades térmicas de intercambiadores de calor en la subestación de calentamiento de la vivienda y la temperatura de retorno de agua caliente sanitaria. Se tienen en cuenta la estrategia de control de recirculación, la longitud de las tuberías de servicio, así como, la distribución en un edificio de tipos de subestaciones con estrategias de recirculación y características similares. Se evalúa el impacto que tienen en las conclusiones de la metodología, las variaciones en las variables de entrada. Se proporciona una comparación de la sensibilidad de las pérdidas en edificaciones con cuatro tipologías diferentes, con 13, 24, 25 y 49 apartamentos. Se llevó a cabo el análisis de sensibilidad, para identificar la influencia de la tipología de las edificaciones en el cálculo de las pérdidas de calor. El estudio se realizó mediante un diseño experimental, que consistió en la combinación de parámetros que se variaron a partir de los niveles previamente fijados. Los resultados muestran la sensibilidad de las pérdidas de calor en función de los diferentes valores de los parámetros de entrada, así como en qué circunstancias cambiaría la variable dependiente. Se demostró la idoneidad del método propuesto que permite una mayor flexibilidad para tomar en cuenta diferentes características de la topología de las tuberías dentro de un sistema de distribución de la calefacción.

PALABRAS CLAVES: Evaluación de sistemas de distribución de calor, Análisis de sensibilidad

INTRODUCTION

Collective heat distribution systems at the level of building or communities (district heating) is seen more and more as an effective solution towards sustainability in the heating sector. In order to evaluate the suitability of the calculation methodology developed in the framework of the ATG-E (Especial Performance Assessment of Energy System, acronym in Dutch) to be used as an improved calculation methods in the context of the Flemish EPB-regulation (Energy performance and indoor climate in buildings) a number of action have been carried out. Several dynamic simulation model have been developed. A survey was sent to manufacturer, supplier or developer of such a system or component intended to identify which are the typical configurations of collective heating systems in the Belgian building sector. A sensitivity analysis of the methodology by means of a global factorial design have been carried out.

The sensitivity of heat losses in collective heat distribution systems by using a simplified heat loss calculation method have been examined. A generalized approach for the development of more accurate heat loss calculation have been used. The approach is applied to a specific type of collective heat distribution system design where networks distributes heat for both space heating (SH) and sanitary hot water (SHW) to the dwelling (the so called Combilus System). The proposed methodology take into account suitable design parameters influencing the thermal performance of a heat distribution system. Hence, the thermal properties of the heat exchanger in the dwelling heating substation and the nominal return temperature of domestic hot water are considered. In addition, the recirculation control strategy and the length of service branch which is included or not during the hot water recirculation period are also taken into account. Furthermore, the method also considers the share of dwelling heating substations, with similar characteristic and control strategy.

SENSITIVITY ANALYSIS OF THE METHODOLOGY

The assessment of the impacts of some potential variations in a selected group of input variables, on the conclusions of the Combilus methodology is conducted through a sensitivity analysis by means of a Global Factorial Design. The efficiency corrector factor (Factor of Eff. also defined as *f_ctrl,combi k*), the efficiency of the Combilus system and more specifically the heat losses in the distribution system calculation method make use of well-known detailed physical relations. This relations describe the way that various disturbances parameters (thermal properties of insulation material, SH and SHW demands, weather conditions, control systems, pipes layout, etc.) influence the thermodynamic behavior of an energy system. Within this equations system a lot of parameters affect the reliability of the calculation results. To overcome these issues, sensitivity analysis is used to quantify how variability's in these parameters influence the conclusions that are made from the model and quantify confidence intervals of the output.

In sensitivity analysis, usually, the approach is to change the value of a numerical parameter through several levels. In much of the studies, researchers use a factorial analysis 2^n with n factors at two levels (low and high). However in the present study a multilevel factorial analysis I^k have been carried out. In this kind of analysis each k factor have a specific number of I levels. Similarly to the 2^n factorial analysis the standardized regression coefficients (SRC) were applied to determine the sensitivity of the selected performance indicators i.e. (Combilus Efficiency, Heat losses and Factor of Efficiency). As was observed by Breesch and Janssens [2], the SRC provides a measure of the effect of the variation of an input on the variation of the output, while all other input parameters equalize their expected value. The statistical model upon which the analysis of screening designs is based expresses the response variable $\hat{y}_i$ as a linear function of the experimental factors, interactions between the factors, and an error term, which can be expressed as:

$$\hat{y}_i = b_0 + \sum_{l=1}^{k} b_l x_l + \sum_{l=1}^{k} \sum_{j=l+1}^{k} b_{lj} x_l x_j + \varepsilon \quad (1)$$

Where

x_i x_j : are input parameters

$\hat{y}_i$: is the response variable

b_0, b_{ij} : are coefficient of the experimental factors

ε : is the experimental error

The experimental error ε is typically assumed to follow a normal distribution with a mean of *0* and a standard deviation equal to σ. The choice of parameter range and distribution type both influence the sampled behavior of the thermal model that is studied. Distribution on the input parameters has been estimated from data in the literature and manufacture information. Hereafter a short description of the procedure to define the range of each parameter is presented.

PARAMETER DEFINITION OF THE SENSITIVITY ANALYSIS

This work is focused on a well-defined section of the physical source of uncertainties and sensitivity influencing the calculation method outputs. Following the selected parameters (factors) to carry out the analysis are presented. While table 1 shows the set of levels for each parameter.

- *Sanitary hot water return temperature* (Treturn_SHW)
- *Degree of combination of substation* (DgComb).
- *Ratio Heat Exchanger Parameters* (RatioHxc)
- *Ratio recirculation Control* [% Pre-heating_On] (RatioCtrl)
- *Service pipe length* (ServP_Lc)

The sensitivity range of the *Sanitary hot water return temperature* (Treturn_SHW) was defined by using information provided by heating substation manufactures. Two levels (low and high) were defined for this parameter. Similarly, two level were also defined for the case of *Degree of combination of substation* (DgComb). This parameter take into account if there are different type of substations in the Combilus system. Substations can have different technical specification in terms of sanitary hot water return temperature, stand by set point temperature, heat exchanger thermal properties among others parameters, therefore this parameter make a distinction between system with an homogenous composition of substations and those system with more diverse configuration (different type of substations).

The *Ratio Heat Exchanger Parameters* (RatioHxc) is a variable which considers the proportion, in a Combilus System, of dwelling heating substation with similar thermal properties in the heat exchangers (i.e. Ahx: heat exchanger area and Rhx: thermal resistance of the heat exchanger). For simplicity only three alternatives of thermal properties (Maximum, Minimum and Middle) were considered. However, in order to evaluate a wide range of existing devices, extremes values considering information of 13 different substations from several manufactures were selected. This parameter is the number of apartments using substation with Rhx maximum, while the rest of apartments use substations with Rhx minimum, however a level where all the apartments have a Middle value of Rhx have been included. This variable presents 6 level, however it is a hierarchical or multilevel parameter, since depending of the level or value of the variable Degree of combination of substation the parameter *Ratio Heat Exchanger Parameters* will be able to take some specific values. Notes that when the variable *Degree of combination of substa*tion take the low level (Not combination) the variable *Ratio Heat Exchanger Parameters* can only take those level where 100% of the apartments have substation which use heat exchanger with the same Rhx properties i.e all of them Maximum, all of them Minimum or Middle.

When considering the recirculation control strategies, two scenarios have been explored. The first scenario is based in a widely used recirculation control system based on centralized and temperature controlled recirculation strategy. In this option a thermostat is controlled using an adjusted set temperature to ensure that the temperature in the supply pipes kept within the operational range of 40°C and 50°C. The bypass valve operating with this controls strategy are usually installed at the top of the riser supply pipe at each stair for the case of multi-family building. The second scenario considers local customer unit controlled recirculation strategy (activation of Pre-heating function in the substation). In this alternative a bypass valve installed in each house substation is considered. The parameter *Ratio recirculation Control* [% Pre-heating_On] (RatioCtrl) represents the proportion of substations with the activation of the Pre-heating function switched ON. To evaluate the impact of this parameter in the depending variables of the methodology, four different level were considered.

The parameter *Service pipe length* (ServP_Lc) is defined as the distance from the collective riser to the substation at each apartment. The sensitivity range of this parameter was defined with 5 levels and it take values from 0 to 10 m. The selection of 10m as the maximum length of the service pipe intends to guarantee the performance of the substation in accordance with the reference values of sanitary hot water comfort prescribed in the European standard EN 13203-1 [2]. The sanitary hot water comfort can be estimated as the mass flow rate that is withdraw at temperatures above 40°C divided by the total hot water use. In addition to the temperature conditions, customer comfort satisfaction is influenced by time required for SHW to reach a fixed temperature level after tapping was started, the so called waiting time, recovery time or tap delay. Based on the same European standard the waiting time tm (s) is defined as the time taken to reach, at appliance outlet, a hot water temperature higher than 44°C.

As have been reported by Kristjansson [3], the state-of-the-art for multi-family buildings of collective heat distribution is the concept where each apartment has own substation, and the SHW and space heating (SH) pipes are in the individual flats laid out only in the horizontal direction. Moreover, it is also considered that the heat distribution systems fulfill the recommendations prescribed in the Best Available Practices for public collective systems in Belgium [4]. Therefore, it is assumed that on the SHW-pipes in the dwellings the water volume is lower than 3l, in order to avoid that water at unsafe temperatures remain still for a long time in the distribution circuit. Additionally, in accordance to best practice and practitioner approach it is assumed that the SHW fixtures should be individually connected with pipes with DN15 or DN10 and maximum length between 15 or 25m respectively, which is seen as enough for a typical dwelling if the location of all SHW tapping points is planned during the design phase of the house [5]. It was also considered the experimental results presented by Brand M [5] regarding influence of service pipes length and bypass solutions on hot water comfort. The author demonstrated that with an external bypass with a service pipe of 10m from an apartment with a shower at 2,2m from the substation the waiting time reach values of 13s and to 17s to produce respectively 40°C and 45°C of hot water. In accordance to the European standards EN 13203-1 [2] and/or the Danish standard DS 439 [6], much of the practitioners and developer define a waiting time bellow to the 10s as an acceptable level of comfort in terms sanitary hot water delivered. Finally, it was taken into account expert criteria as a result of interviews with manufacturer which recommends the activation of the preheating function when the distance from the riser to the substation is larger than 10m. All this elements underline the definition of the 10m as a maximum length of the service pipe.

Table 1. Set of levels for each parameter.

Parameter	**Variable Name**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Level 6**
Sanitary Hot Water return temperature	Treturn_SHW	25°C	34°C	-	-	-	-
Degree of combination of substation (Yes /Not)	DgComb	Yes	Not	-	-	-	-
Ratio Heat Exchanger Parameters {Rhx} (Max/Min) [%]*	RatioHxc	100% Max	75% Max	50% Max	100% Midd	25% Max	0% Max
Ratio recirculation Control (% Pre-heating_On)	RatioCtrl	0 % +16%	33 % ±16%	66 % ±16%	100 % -16%	-	-
Service pipe length (individual per apartment)	ServP_Lc	0 m +1,25m	2,5 m ±1,25m	5 m ±1,25m	7,5 m ±1,25m	10 m ±1,25m	-

* A level where all the apartments has a (Middle) value of Rhx around to the average between the maximum and the minimum values have been included.

RESULTS AND DISCUSSIONS

Firstly, the influence of the input parameters variation on the different terms of the calculation method, step by step, were studied. Therefore, before to carry out the global sensitivity analysis of the calculation method a one at a time (OAT) analysis focuses on the influence of *Service pipe len*gth (ServP_Lc) parameter was conducted. The OAT analysis allow to evaluate the responds of the system as a result of the variation of the Service pipe length while all other parameters were hold with a constant value. The OAT analysis was carried out for a condition where the 13 apartments have not the Pre heating function activated and each substations uses a heat exchanger with "Middle" thermal properties (table 1).

When analyzing the behavior of the Combilus system by mean of an OAT analysis the interaction of the *Service pipe length* with other parameters is missed, since all the rest of parameters remind constant. A global sensitivity analysis where all parameters are changing will allows to identify the interaction of parameters and eventually a possible non-lineal dependence of the model to a given input parameter. Accordingly, hereafter the 156 cases of the multilevel factorial analysis are further investigated in terms of influence to the different components of the whole calculation method. Results of the 156 cases investigated denotes that the total heat loss obtained with the ATG-E methodology is significantly lower than the ones obtained with the actual EPB method. However, results varies strongly with values from 121 GJ to 146 GJ with average heat losses of 133 GJ. Hence, to identify the influence of the different factors a global analysis of the sensitivity was conducted.

Figure 1 displays the result of the Efficiency of the Combilus system according to the ATGE and the current EPB calculation method. In addition the values of the corrector factor "*f_ ctrl,combi k*" is plotted, as well. In the graph, results have been ordered in descending values of the Efficiency of the Combilus system calculated according to the current EPB method. The six different cluster of results are due to the six different level of proportion of substation with similar heat exchanger characteristic. The expected inverse proportionality in the relation between the efficiency corrector factor and the efficiency is verified.

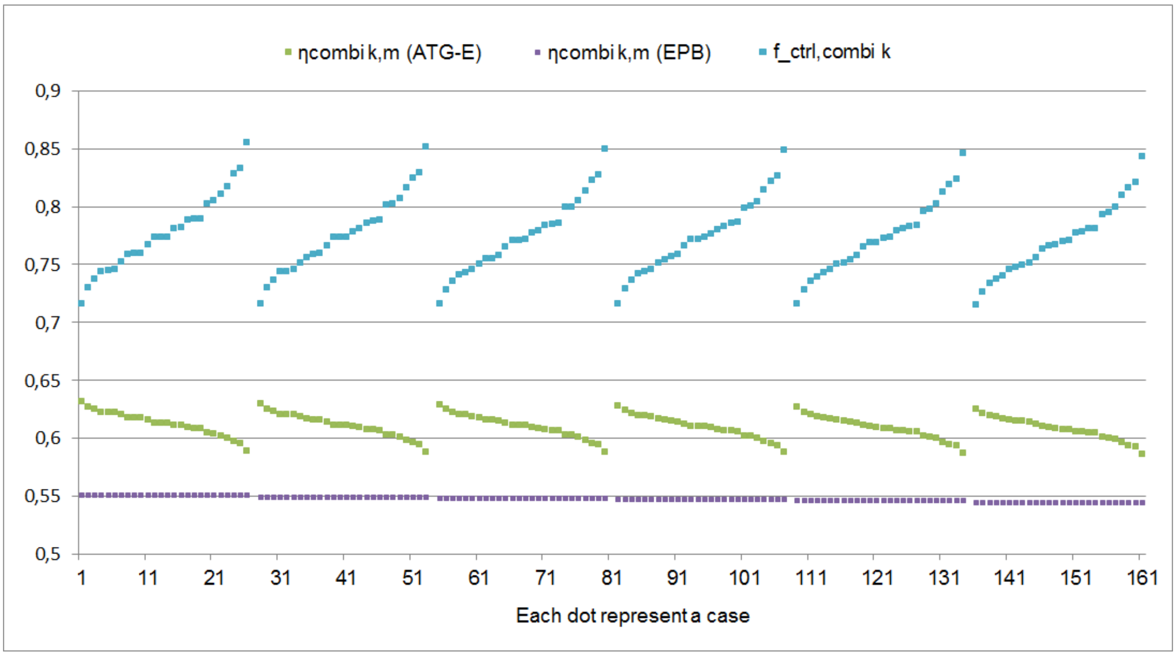

Figure 1. Corrector factor "*f_ctrl,combi k* " and Efficiency of the Combilus according to the ATGE and EPB

For each case the *f_ctrl,combi k* (Eff_factor) was calculated using the ratio of the heat losses calculated with the ATG-E methodology to the heat losses of the original EPB calculation. The values of the *f_ctrl,combi k* were used as dependent variable to evaluate the sensitivity of this variable in function of the variation of the input parameters. The graphic shows that the *Service pipe length* (ServP_Lc) is the most important factor for the sensitivity of the *f_ctrl,combi k* (Eff_factor). Combinations between the *Ratio Heat Exchanger Parameters*

(RatioHxc) and the Service pipe length as well as between the *Sanitary hot water return temperature* (Treturn_SHW) and Service pipe length have also a significant influence on the *f_ctrl,combi k* variability. Based on the result of the global factorial analysis it was possible to define the best combination of independent variables to characterize the behavior of the system heat losses. Hence, five different alternatives of combination of parameters to define clusters of system characteristic were analyzed. Alternatives with 16, 12, 10, 6 and 5 categories were compared in terms of how well each category, within an alternative, was able to represents a clusters with similar behaviors. The alternative with 6 categories was selected as the best compromise between the number of categories and the capability of each category to represent similar responds of the system to a given combination of input parameters. Table 2 and figure 2 summarizes the selected alternative of parameters combination as result of the sensitivity analysis. In contrast with table 1 where each parameter was represented by its mean values in table 2 and figure 2 the range of each category is presented.

Table 2. Proposal of potential default *f_ctrl,combi k* values as function of system pentameters

Service pipe length	Pre-heating_On	f_ctrl,combi k
0-11,25m	84-100 %	0,73
0-6,25m	17-83 %	0,76
	0-16 %	0,78
6,26-11,25m	50-83 %	0,76
	17-49 %	0,79
	0-16 %	0,82

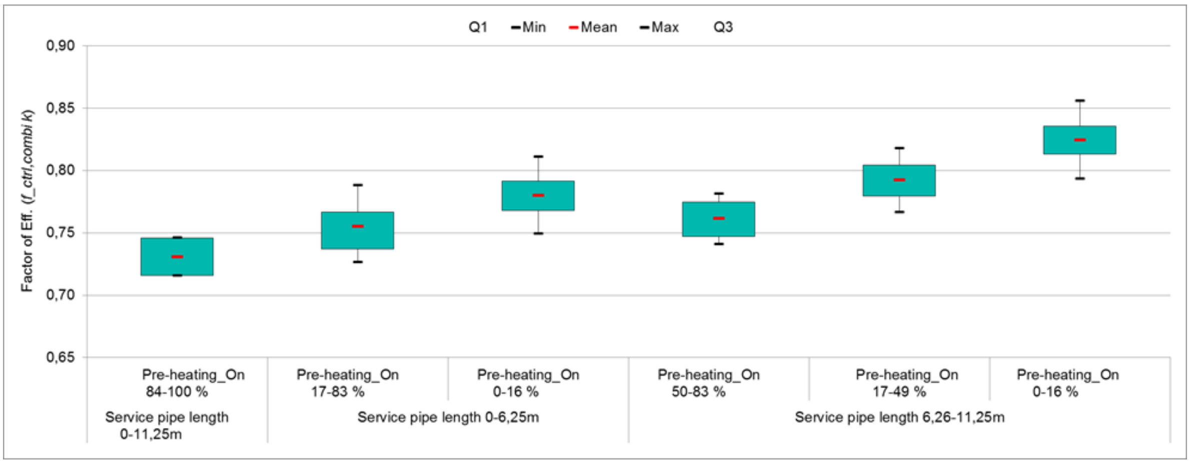

Figure 2. Box chart of *f_ctrl,combi k* values as function of system pentameters

Results denote that each category presents a normal distribution and small variability of the values within the category. When more than 85 % of the apartments of a Combilus has the Pre-heating function activated the system presents the smaller values of *f_ctrl,combi* factor (0,73). This result reflects that a good balance is achieved between the heat losses during stand by condition and the heat losses in the distribution system during SHW operational condition. In this situation, this category is independently to the length of the service pipes, since the state of the system is dominated by the condition of the majority i.e 85 % of the apartments. When the length of the service pipe is in the range of 0 to 6,25m the *f_ctrl,combi* factor value remind bellow 0,78. When the service pipe is in the range of 6,26 to 11,25m, the values of the efficiency corrector factor increases. In this case three categories according to the amount of apartments with the Pre-heating function activated were defined. When the number of apartments with the Preheating function activated is larger than the 50%, the *f_ctrl,combi* factor presents value of 0,76. However, when the number of apartments with the Pre-heating function switched ON is below to 16% the *f_ctrl,combi* factor increases up to 0,82.

Heat exchanger heat losses analysis.

When analyzing the results of the global factorial analysis in terms of the variability of the heat losses in the heat exchanger, the influence of this component of the substation in the total heat losses can be identified. Figure 3 (left) shows the percent of the heat losses in the heat exchanger with respect to the total heat losses of the Combilus system for the 156 cases. In the graph each dot represents a given case. A small variability can be identified with values from 0,5% up to 4,5% and average of 1,8% of the heat losses in the heat exchanger with respect to total heat losses. Result denotes that heat losses in the heat exchanger are not significant in comparison to the heat losses generated during operational conditions, i.e. hot water, wasting water and/or stand by conditions. In figure 3, (on the right), this difference have also been highlighted. The graph shows the estimation of the ratio of the heat losses in the heat exchanger calculated with the methodology to the heat losses in the heat exchanger estimated with the current EPB method. In the graph, results are presented in per cent and reflects that the heat losses in the heat exchanger calculated with the new methodology render values between 38 and 72% of the values obtained with the current EPB methods.

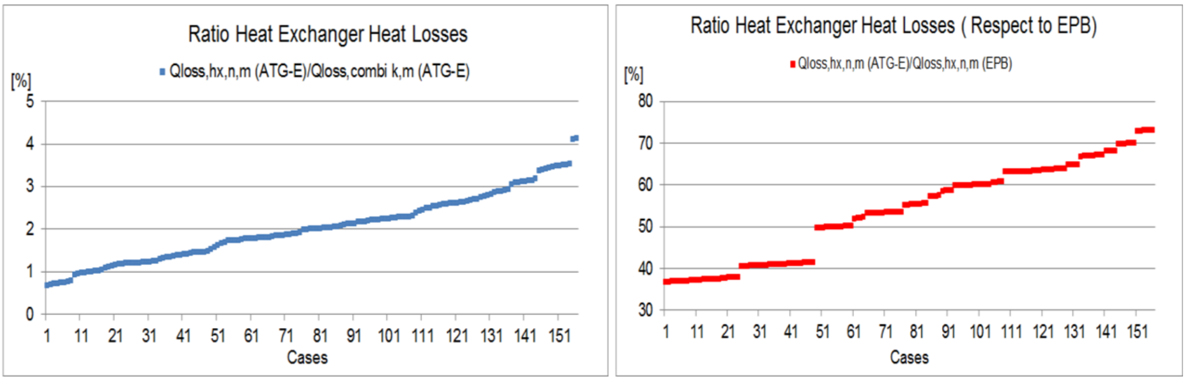

Figure 3. Percent of heat losses in the heat exchanger respect to the system and the current EPB method

Sensitivity analysis of heat distribution system heat losses in four different buildings

In order to investigate the influence of building typology and different Combilus system configuration, a comparison of the sensitivity analysis results of four different buildings was carried out. In addition to the base case building with 13 apartments, three different Combilus system with 24, 25 and 49 apartments were analyzed. The Combilus system of building 1 and building 4 respectively with 13 and 49 apartments are based on study cases provided by Flemish Energy Agency. Building 3 with 25 apartments and the case of building 2 (24 apartments) corresponds with the specification of existing building. Figure 4 displays the different building typologies, while table 3 presents the design specifications of the four buildings investigated.

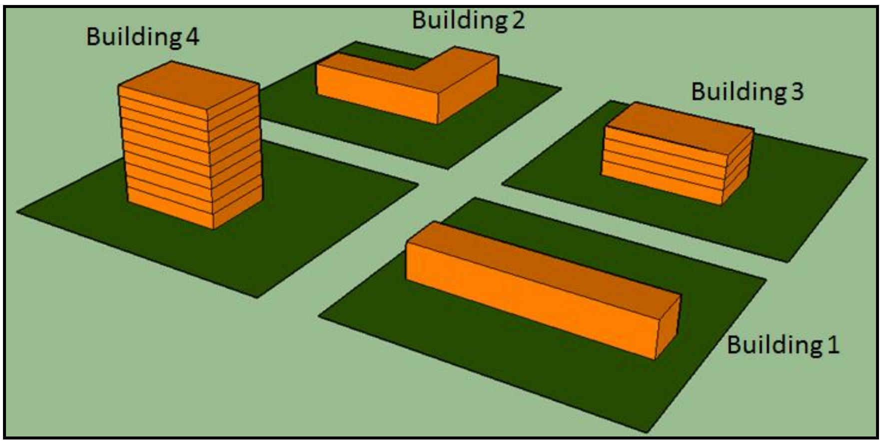

Figure 4. Typologies of the buildings investigated

Table 3. Design specification of the four buildings investigated.

Combilus System specification	**Building 1**	**Building 2**	**Building 3**	**Building 4**
Number of apartments	13	24	25	49
Sum of Volume of energy sectors [m³]	3976	6685	10172	10120
Total length pipe distribution system [m]	544	303	290	642
Design supply temperature of the energy sector [°C]	60	48	60	45
Design return temperature of the energy sector [°C]	50	33	40	35
Water return temperature during Stand by [°C]	45	45	45	45
Net energy demand for SHW [GJ/year]	46	79	110	132
Net energy demand for SH [GJ/year]	126	82	239	118
Heat delivered by the Combilus (Qout, combi k,m) [GJ/year]	207	191	390	295
Characteristic primary energy use [GJ/year]	528	849	1590	505

Although the information provided in tables 3 give an idea of the difference between the selected Combilus system, a number of indicators have also been defined (see table 4). The definition of the indicators aims to normalize the specification of each Combilus system providing a better characterization of the system. The first indicator is the *Cooling capability* of the Combilus system, this parameter is traditionally estimated in district heating using actual measurement data of return and supply temperature of the building coupled to the network. In the present study to estimate this indicator, the information regarding design supply and return temperature have been used. A larger differential value between the supply and return temperature guarantee a lower value of flow rate to cover similar energy demand, which contributes to the reduction of pipe cost and pumps exploitation during operational condition. Another indicator to compare the characteristic of the Combilus system is the *Heat density* in terms of Combilus heat output per meter of distribution pipe (MJ/m). A heating distribution system can also be characterized by the *Ratio of heat demand* (Space heating demand to the Sanitary hot water demand). A further indicator to highlight the difference of the system is expressed through an *Equivalent linear thermal resistance* of the pipes forming the distribution system $R_{l,eqv}$ (mK/W). This indicator give an indication of the thermal properties of the distribution network by means of a weighted average of the linear thermal resistance based on Eq. (2).

$$\frac{1}{R_{l,eqv}} = \frac{\sum\left(\frac{l_{combi,k,j}}{R_{l,j}}\right)}{\sum l_{combi,k,j}} \qquad (2)$$

Where:
$l_{combi,k,j}$ is the length of a pipe segments in the Combilus
$R_{l,j}$ is the linear thermal resistance of the pipe segments in the Combilus.

The E-level values, or 'level of primary energy use', which reflects the energy performance of a house in the Belgian regulation were not available for the four studied buildings. For that reason an indicator, (*Primary Energy level*), based on the available information of the characteristic primary energy use and volume of the energy sector was estimated. This indicator was calculated using the methodology presented in [8], which consider the transmission losses surface of an average building presenting similar Volume than the study case. The transmission surface is estimated by using the surface of the sphere with similar volume the building energy sector, corrected with a factor validated by means of the application of this approach to the whole Flemish Energy Agency database of building stock. For reader more interested in the detailed of this approach a comprehensive description of the new concept can be found in [8]. Table 4 present the values of the different indicators for the selected buildings.

Table 4. Indicator to characterize the Combilus system of the selected buildings.

Combilus system indicator	Building 1	Building 2	Building 3	Building 4
Cooling Capability	10	15	20	10
Heat density in terms of Combilus heat output per meter of distribution pipe of MJ/m	381	630	1343	459
Ratio Space heating demand to Sanitary hot water demand	2.8	1.0	2.2	0.9
Equivalent linear thermal resistance of the pipe Rl_{eqv} (mK/W)	4.5	2.4	5.2	5.2
Characteristic primary energy use per Average transmission losses surface corresponding to the Energy sector Volume	112	128	181	58

For each building, the 156 cases defined in the global factorial analysis were calculated. Figure 5 displays the variability of the heat losses in the heat exchanger for the different Combilus system analyzed. The graph shows the percent of the heat losses in the heat exchanger with respect to the total heat losses of the Combilus system for the 156 cases. Results denotes that the fraction of the losses belonging to the heat exchanger is significantly depending of each specific case. While a small variability can be identified in the building with 13 apartments, which take values from 0,5% up to 4,5% and average of 1,8% of heat losses in the heat exchanger with respect to total heat losses, in the case of the building with 25 and 49 apartments the heat exchanger losses take values from 0,6 till 14% of the total heat losses of the Combilus. Result denotes that depending of the specification of the Combilus system the heat losses in the heat exchanger can be relatively significant or not in comparison to the heat losses generated during operational conditions, i.e. hot water, wasting water and/or stand by conditions.

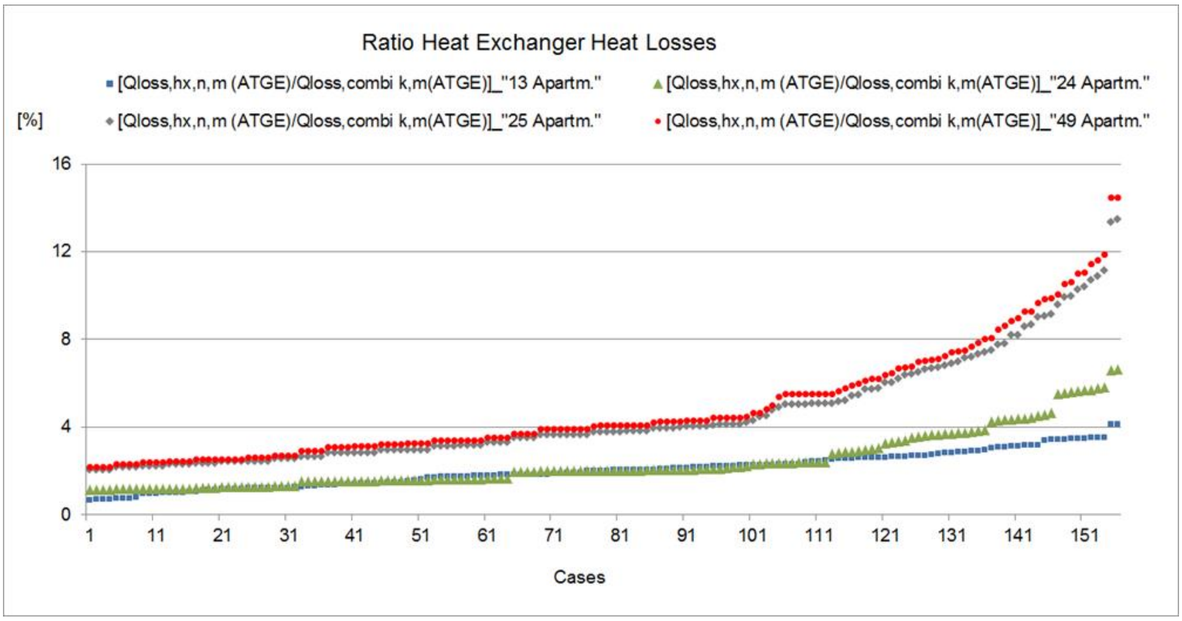

Figure 5. Heat losses in the heat exchanger respect to the Combilus heat losses for the buildings analyzed.

In addition, figure 6 presents the estimation of the ratio of the heat losses in the heat exchanger calculated with the ATG-E methodology to the heat losses in the heat exchanger estimated with the current EPB method. In the graph, results are presented in per cent and reflects that the heat losses in the heat exchanger calculated with the ATG-E methodology render values between 30 and 73% of the values obtained with the current EPB methods.

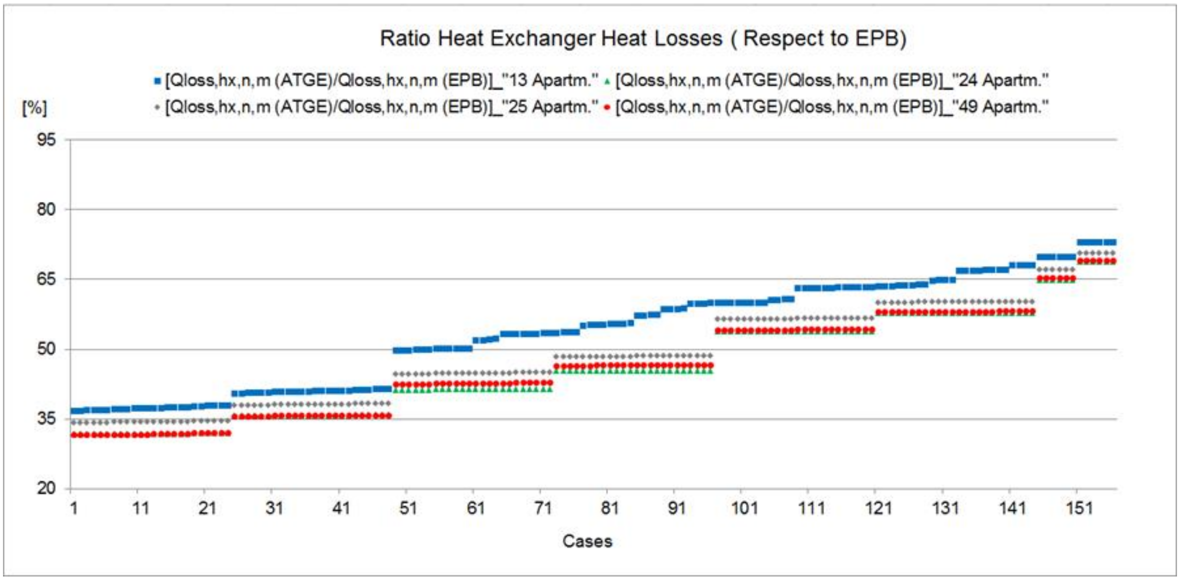

Figure 6. Percent of heat losses in the heat exchanger respect to the results with the current EPB method.

Figure 7 summarizes the results regarding the corrector factor *f_ctrl,combi k* obtained from each building. Results demonstrated that the efficiency corrector factor is significantly case specific sensitive. The corrector factor *f_ctrl,combi k* take values in the rage of 0,65 till 0,88. The size of the building in terms number of apartments or length of the distribution pipes are not able to explains the variability of the result. Notes that the Combilus system of Building 4 (49 apartments) presents on average lower results than those of Building 1 and Building 3 respectively with 13 and 25 apartments. Similarly Building 2 with 24 apartment has lower values than the rest of the cases including Building 1 with 13 apartments.

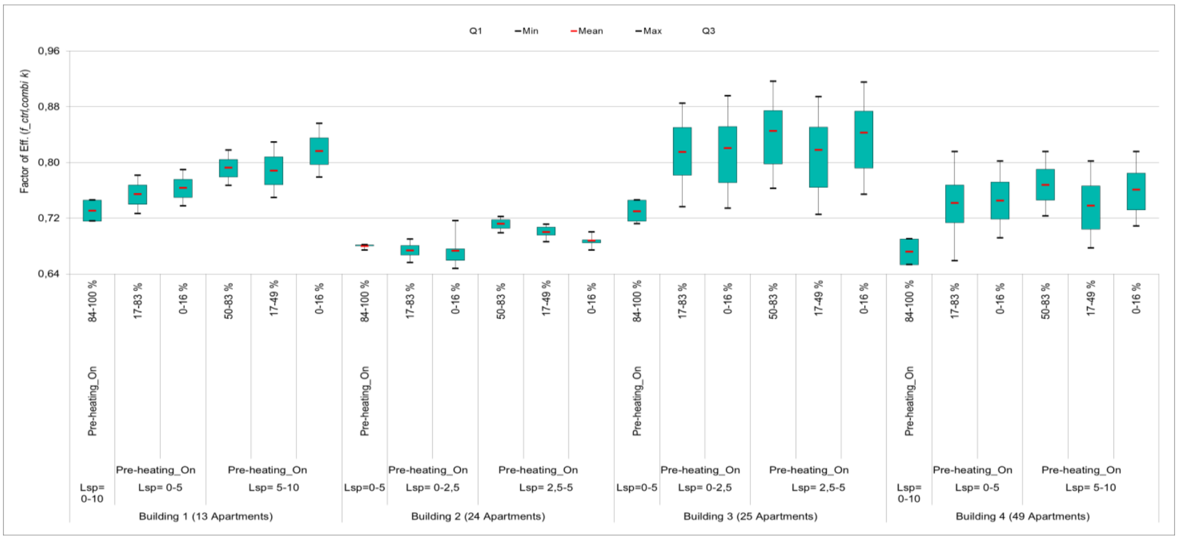

Figure 7. Corrector factor *f_ctrl,combi k* obtained from each building.

The combination of the different system specifications can significantly influence the variability of the results. It is remarkable that Building 4 and Building 2 presents the lower values of f_ctrl,combi k. These two buildings are the ones which present design supply temperature of the energy sector lower than 60°C. Independently that other parameter are influencing the result that could be an explanation why these two buildings present the lower values. It is well-known that the heat losses calculation in the current EPB is based in the assumption that the average temperature inside the pipes is as less as 60 °C. Therefore, it is expected that in buildings with design supply temperature lower than the current EPB assumption, the heat losses calculation considering actual design temperature will reach larger difference than those buildings which design supply temperature close, equal or larger than 60 °C. When comparing different buildings, the efficiency corrector factor f_ctrl,combi k is not able to describe the performance of a Combilus system. Lower values of *f_ctrl,combi k* does not necessarily means better performance of the system but that the results are much more different that the one obtained with the current EPB calculation of this specific Combilus. Following graphics focuses on heat losses and the efficiency of the Combilus system verify the right interpretation of the corrector factor results.

Figure 8 displays the result of the heat losses of the different Combilus systems investigated. Result denotes that building 3 presents the lower heat losses but, at the same time, the lower difference with the current EPB heat losses calculation method. Since heat losses are case specific, the graph only show how far or not are the calculation of a given case from his own EPB calculation result. To get a whole overview of Combilus system the heat delivery by the system has also to be considered.

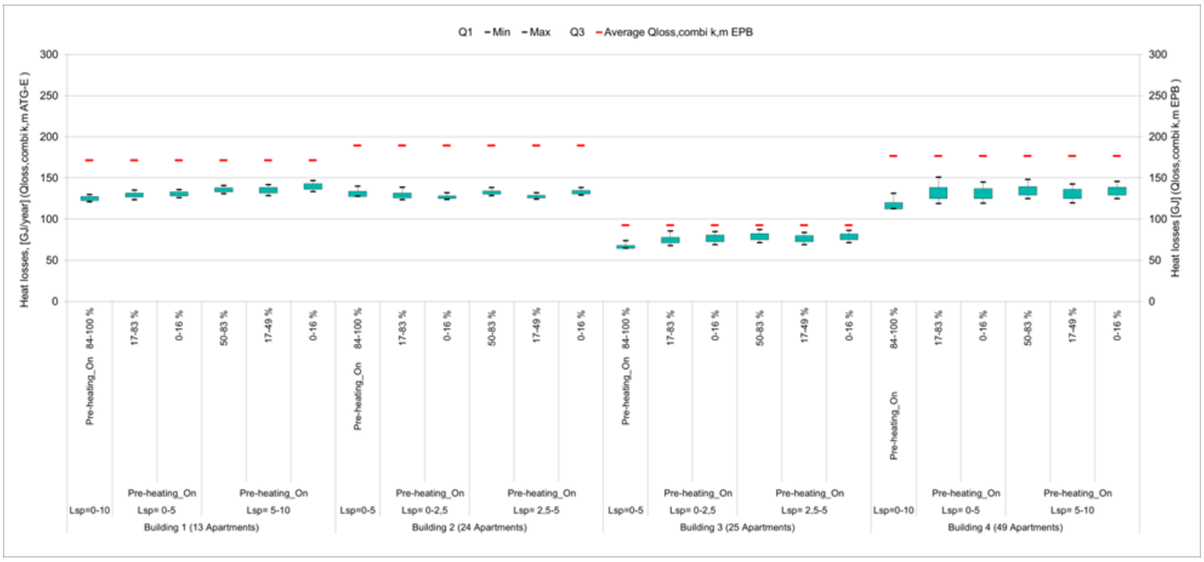

Figure 8. Heat losses in the Combilus, 156 cases of the buildings investigated

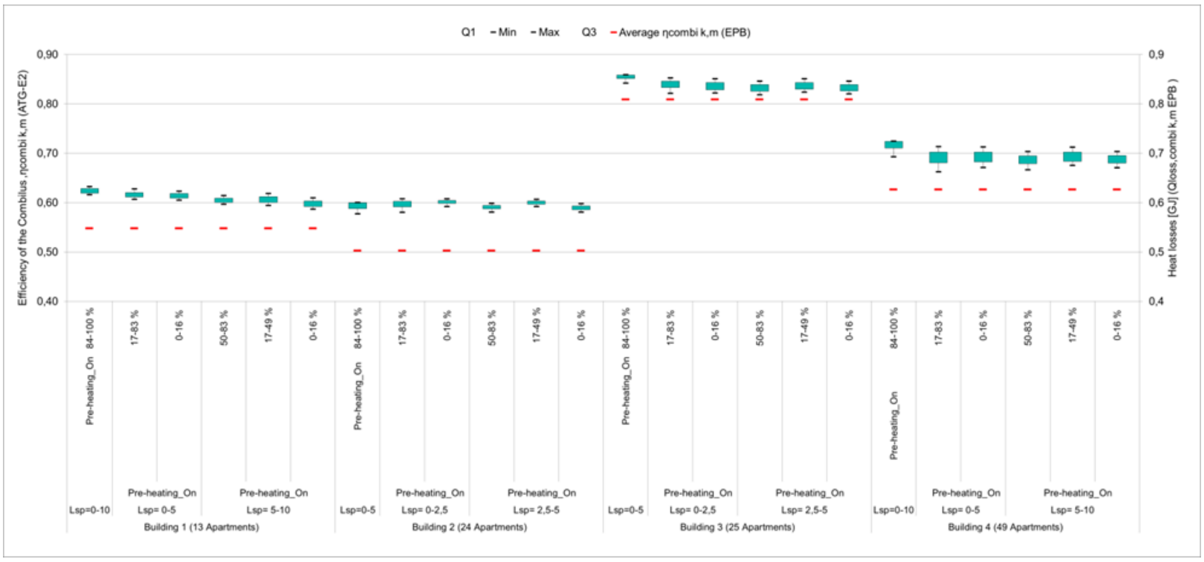

Figure 9. Efficiency of the Combilus according to the ATGE and the current EPB of the buildings analyzed.

Although, is the efficiency of the system the suitable parameter to evaluate the performance of different Combilus system, all the present study focusses on identify how far or not are the results of the heat losses calculated with the ATG-E methodology to the one obtained with the current EPB method. On the other hand, figure 9 shows the result of the efficiency of the different Combilus systems. Results denotes that in contrast with variability of the corrector factor, within each building there are a small variability of the efficiency. Building 3 present the higher values of system efficiency but also the smaller difference with respect to the results obtained with the current EPB calculation method.

CONCLUSIONS

The sensitivity of heat losses in collective heat distribution systems using a simplified calculation method was investigated. The impacts of some potential variations in the input variables, on the conclusions of the methodology was assessed. A comparison of the sensitivity of heat losses in the heating distribution system between four different buildings typologies, i.e. with 13, 24, 25 and 49 apartments, was carried out. In order to identify the influence of building typology and pipe layout in the heat losses calculation, for the four cases the sensitivity analysis was discussed. A sensitivity analysis by means of an experimental design, consisting of the combinations of parameters which were varied from the levels at which they were set was conducted. Results shows how sensitive the solution is in the face of different parameter values as well as under what circumstances the solution would change. The suitability of the improved method which allow more flexibility to consider different pipe layout characteristic within a heating distribution system was demonstrated.

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