Impact of Building Airtightness on Heat Generator and Heat Emission Equipment Sizing

Sébastien Pecceu, MEng **Paul Van den Bossche, MEng**

ABSTRACT HEADING

Cracks in building fabric lead to air infiltration due to wind and buoyancy driven forces. In the heating season, the cold air entering the building needs to be heated up to room temperature, thus leading to an energy demand. Conventionally, the measured infiltration rate at 50 Pa (expressed as n50 or q50) is recalculated into an average infiltration flow rate (yearly based) using leak infiltration ratio's (LIR) ranging from 0.033 to 0.1, the origin of these values being sometimes unclear. Apart from the yearly based energy demand, heating load calculations (according to the standard EN 12831-1) are used to size heat generators and heat emission equipment and require leak infiltration ratios on a short-term base (1 hour – 1 day). It can be expected that this short-term evaluation leads to much bigger LIR's.

The BBRI investigated the infiltration rates, using CONTAM simulations on some typical dwellings. This paper presents the results of these simulations, and reports on various dwelling properties, influencing the actual infiltration rate, among others: the infiltration rate at 50 Pa, the ventilation system, the distribution of leaks over the building envelope, the variable temperature and wind conditions, even in a small country as Belgium, the shielding of the building, height and orientation. 2 important conclusions will be reported on: first the leak infiltration ratio at room scale can be much higher than at building scale, and third; because the actual leak infiltration is mainly wind-driven and the strongest winds in Belgium occur at higher outdoor temperatures (and not the lowest design temperature) in some building configurations the biggest heat load doesn't occur at the lowest design temperature, but at somewhat higher temperatures.

INTRODUCTION

Airthightness measurements of buildings are performed to determine the air infiltration rate of building fabrics. The measurement generally occurs at relatively high pressure differences (and its result expressed as q_{50} or n_{50}, at 50 Pa) and can then be used as input for energy related calculations. The real-life infiltration rate is variable in time and space since it is driven by natural forces (wind, thermal stack) that are variable by nature (in both time and space dimensions). It is common in standards or energy performance reglementations to consider that the yearly mean value is a fraction of this q_{50} value, using a Leak Infiltration Ratio (LIR). A commonly used rule, known as the rule-of-20, consist in using an average infiltration rate of $q_{50}/20$ (LIR=1/20=0.05). The origin of this rule and other common values is discussed in Jones and al. (2016), which concludes that this rule of thumb is only a rough approximation and that LIR are building and location specific.

Even though yearly average values may make sense in an energy performance perspective, it may not be relevant for the sizing of heat generators or heat emitters that should be able cover the peak heat demand. In the context of heat equipment sizing, the time scale is much shorter and higher LIR's should probably be considered. The currently applicable standard in Belgium is based on EN 12831-1. The national annex of this standard details how the ventilation and infiltration losses are to be computed for heating system design. The heat demand is computed on a basis of daily average values for both transmission and ventilation/infiltration losses. Regarding infiltrations, a LIR value of 0.1 is prescribed as well for the building (heat generator) as for the spaces (heat emitters).

Sebastien Pecceu and **Paul Van den Bossche** are researchers in the HVAC department of the Belgian Building Research Institute (BBRI).

SIMULATION METHODOLOGY

General hypotheses and building models

All numerical simulations have been carried out with the CONTAM multizone software (Dols & Polidoro 2015).

Natural flow paths have been modeled with appropriate power law flow models, and mechanical supply and extract devices are represented by perfectly constant flow rates.

The external conditions (temperature, wind direction and velocity) will have an impact on the infiltration flow rate and are defined by weather files. The wind pressure is computed for every opening using the actual velocity in the weather file, tabulated pressure coefficients (Cp values, Liddament, 1996), and the so-called "wind speed modifier" that takes into account the difference of reference height and of ground roughness of the building site and the weather station. Four different building models have been used. They mainly differ by the floor plan layouts and the number of free facades (short name between parenthesis): 2 storeys detached house (DH), 2 storeys semi-detached house (SDH), 2 storeys terraced house (TH), single storey detached house (SSDH).

Building leaks

General formula. In Belgium, the airtightness performance of buildings is expressed at a pressure difference of 50 Pa. The resulting flow rate (q_{50} in m^3/h), is generally normalized either by the internal building volume V_{int} ($n_{50} = q_{50}/V_{int}$) or by the exterior envelope surface S ($v_{50} = q_{50}/S$). In the present paper, we used v_{50} as parameter since leaks are physically more linked to the surface than the the occupied volume[1]. Leaks are represented by the usual power law of type $\boldsymbol{Q = C\ (\Delta p)^n}$, with the commonly accepted exponent n=0.66.

Leak distribution. The global leak deduced from an airtightness measurement has to be distributed over the envelope of the spaces. To our knowledge there is no widely accepted hypothesis over leaks distribution as it is very case dependent. Therefore, we chose to repeat our analysis with several distributions to see if it leads to significant change in the results. The envisaged leak distributions are:

- A perfectly <u>uniform surface-based distribution</u>: the leaks are distributed for each surface according to the area in contact with the exterior. This means applying a constant v_{50} value on all exterior surfaces of the model. In this hypothesis, we include both roofs and floors.
- A <u>uniform distribution only on facades</u> (vertical walls). If the building is directly built on ground and has a watertight (flat) roof, the leaks on floor and roof may be neglibible. In this case, the leaks are uniformly distributed on vertical walls, but with <u>a constant total leak</u> (q_{50}) compared to the uniform case

A <u>non-uniform distribution</u>. In reality, we have very little insight on the true distribution of leaks across the building. Therefore, we also applied pseudo-random leak distributions, considering that the leaks are distributed according a know distribution (normal distribution with Interquartile range – IQR – equal to 75% of the mean v50 value - (Guyot and al., 2016)). For each case, the simulation is repeated 10 times with a new random distribution. This is not sufficient to be statistically meaningful but allows to give a rough estimate of the variability of the results.

Weather data

From preliminary simulations, it is clear that the infiltration rate is mainly driven by wind rather than inside-outside temperature difference. In the context of heating system sizing, we should consider the worst possible conditions. However, we also know from local weather observations (for Belgium) that the highest wind velocities (leading to high

---

[1] The measurement of the air permeability of buildings is generally conducted according to the international standard EN ISO 9972: Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method:2015. The resulting n_{50} or v_{50} values might not be comparable between countries due to different building preparation method or country specific conventions in volume or area calculation, treatment of uncertainties, etc.

infiltration rates) do not occur simultaneously with the lowest exterior temperature. This is illustrated in Figure 1 below. Therefore, it is not possible to a priori define the most penalizing condition regarding the power demand due to air infiltration. As a consequence, simulations have been carried out on the whole set of weather data. Ten years weather data for 3 locations in Belgium (Sea, Center and South) have been used in order to show the possible differences due to location, even in a small country as Belgium.

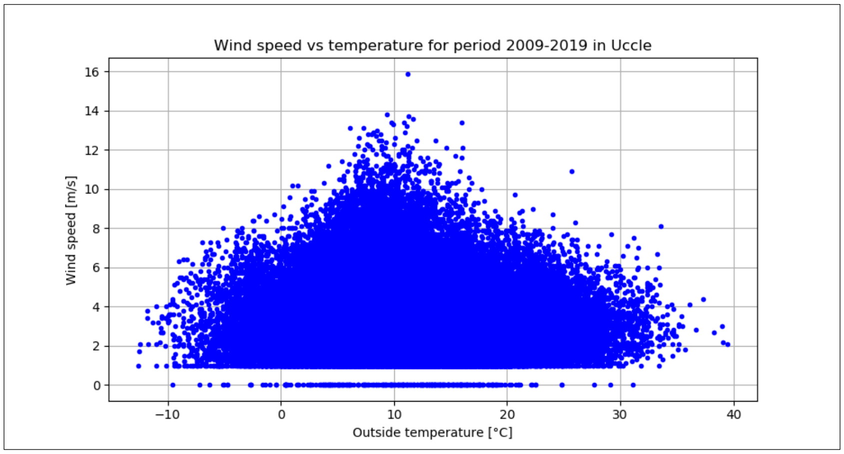

Figure 1 Wind speed versus outside temperature from the period 08/2009 to 07/2019 in the Uccle (Brussels) Royal Meteorological Institute weather station – hourly data

Other considered parameters

Ventilation system. The type of ventilation system will have an impact on the total infiltration flow rate and its repartition. Four ventilation systems are described in the applicable Belgian Standard for residential ventilation (NBN D 50-001:1991): A (natural supply and natural exhaust), B (mechanical supply and natural exhaust), C (natural supply and mechanical exhaust, i.e. Mechanical Exhaust Ventilation – MEV), and D (mechanical supply and mechanical exhaust, in most of cases Mechanical Heat Recovery Ventilation – MHRV).

System B is extremely rare in Belgium. Only systems A, C and D have thus been implemented in the model. A "None" case has also been studied in order to have a reference to compare to and because a lot of existing dwellings do not have any ventilation system (the installation of a ventilation system is mandatory only since begin 2010's in Belgium).

Orientation of the building. The actual infiltration rate and its repartition across the building are obviously dependent on the building orientation with regard to the dominant winds. Four building orientation have been studied (90 degrees step).

Building location/environment. Independently of chosen weather station (corresponding to the geographical area), the direct environment of the building (e.g. shielding) will also impact the infiltration rate. Each building has been simulated with several terrain roughness categories that define the building environment (II: farmland, III: suburbuan, IV: urban). In the simulation, these categories impact the above mentioned 'wind speed multiplier'.

ANALYSIS METHODOLOGY

Computation of infiltration and leak infiltration ratio

The focus being to compute the heat load due to air infiltration, the infiltration rate must be differentiated from the hygienic ventilation rate. It's not is not always straightforward: for example, for a MEV system, a part of the nominal supply flow (that should normally enter through the natural supply vents) will always enter through the cracks (due to underpressure induced by the extraction fans). However, if the total supply flow does not exceed the nominal desired hygienic flow rate, it should not be considered as an infiltration (it does not increase the design heat load since ventilation is already considered in the calculation). Following this logic, the infiltration flow rates at each time step are computed this way (for each individual space or for the building as a whole):

$$\boldsymbol{Q_{inf,space} = \sum Q_{in,space} - \sum Q_{supply\ nom,space}}$$

with

- $Q_{inf,space}$ the infiltration flow rate [m³/h] in the space (building)
- $\sum Q_{in,space}$ the sum of all the <u>incoming</u> flow rates [m³/h] in a space (building): mechanical, natural supply vents or cracks
- $\sum Q_{supply\ nom,space}$: the sum nominal supply flow rate [m³/h] of the considered space (building)

This ensures that only the flow rate above nominal one is considered as infiltration. The consequences of this way of computing are:

- For C system (MEV)
  - no distinction is made between air entering through the natural supply vents or the air entering through the cracks as long as the total flow rate does not exceed the nominal supply flow rate.
  - an overflow through natural supply vents is also considered as infiltration
- For A system (fully natural), the infiltration rate may be lower than 0 if the natural driving forces are not sufficient to deliver the nominal flow rate (i.e. the actual flow rate is lower than the nominal one). In that case infiltration is considered as 0.
- The infiltration rate at building level can be 0 (e.g. building in underpressure), while the infiltration rate computed separately for each room may not be 0. Said otherwise, the sum of the infiltration rates at space level will always be higher than or equal to the building infiltration rate.

For each time step, the leak infiltration ratio can simply be computed by (with A_{space} being the area in contact with the exterior for the considered space), with a corresponding formula at building level:

$$\boldsymbol{LIR_{space} = \frac{Q_{inf,space}}{A_{space}\, v_{50}}}\ [-]$$

LIR as a function of outside temperature

The simulation output gives one flow rate value for each space/building and for each hour. With the presented simulation and postprocessing methodologies, the LIR can easily be computed for each space of the reference building for all combinations of parameters. As we are primarly interested in peak heating power demand, only extreme cases are of interest. We decided to present the results as a function of the outside temperature (as we highlighted earlier the link between wind velocity and temperature), and to retain only the percentile 99 in each slice of 1°C. The choice of p99 is an arbitrary one, to elimitate outliers. The process is illustrated in Figure 2. The example shows the rationale for hourly infiltration flow rate, but it can be applied for any other time basis. The results in the next sections are presented with a time basis of 24H to be consistent with the current standard.

SIMULATION RESULTS

Results at building scale

More than 1000 simulations have been carried out to analyse the effect parameter variations, either one-by-one, either combined. Only the most significant findings can be illustrated here.

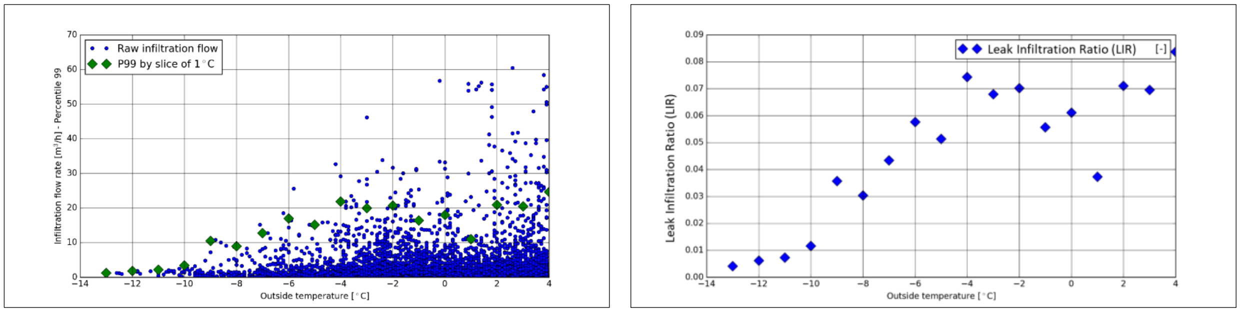

Figure 2 Example of hourly infiltration flow rate for 10 years simulation (left). Percentile 99 is computed for each slice of 1°C (green diamonds). The right figure shows the resulting LIR per 1° slice (computed from the p99 flow rate) for the considered building.

The first finding is that LIR is strongly dependent of the ventilation system for high airthigthness (low v_{50}). For C system (and A system in a lesser extent), the building is globally in under-pressure with regard to outside. This tends to prevent excessive supply flow rate (i.e. infiltration flow rate) through cracks, resulting in low LIR.

For D system and ”None”, the average pressure within the building is closer to 0, allowing more in and out flows through cracks. LIR is however higher for D system than for ”None”, since the mechanical supply tends to impose light overpressure in dry spaces (outgoing flow through cracks) and the mechanical exhaust causes a light underpressure in wet spaces (incoming flow through cracks). The above rationales are particularly true at low temperatures since there is little wind (little disturbances). At higher temperatures (higher wind), the difference becomes smaller.

One must also remark that the difference between systems becomes smaller as the airthightness becomes worse (v_{50} increases). The right figure 3 shows LIRs for the same building configuration with v_{50} = 12. The LIR values do not change much with v_{50} when there is no ventilation system. Note also that whatever the parameters, the p99 LIR increases with the outside temperature, which reflects well the weather data presented earlier.

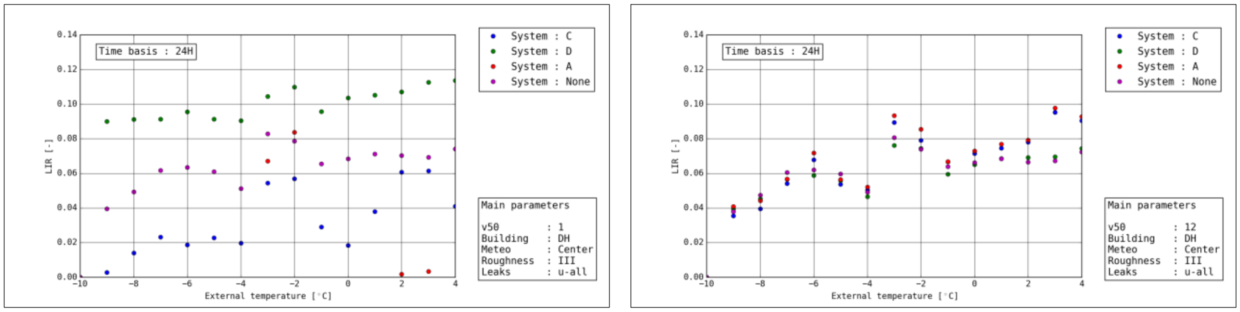

Figure 3 Impact of the ventilation system on the LIR at high airtightness (v_{50} = 1 m³/hm², left) and low airtightness (v_{50} = 12 m³/hm², right). Differences are strong at good airtightness while there is little to no difference at low airtightness.

Other interesting results of the sensivitity analysis are that the local weather has an impact on the LIR even in a small country as Belgium. Typically, there is more wind a Sea, but the lowest extreme temperatures are higher. On the contrary, the temperatures are generally lower in the South of the country (higher altitude), and this can be combined with some wind. These effects have a direct impact on the LIR values as a function of temperature as it can be seen on the left plot of figure 4.

Finally, it is interesting to see that the building typology has only a limited impact on the LIR values, as illustrated on the right plot of Figure 4. A statistical analysis of all simulations show that they are slightly lower for the single storey building, but not in significant order of magnitude (not presented here). Note that the presented LIR values are relative to v_{50} of the building: the absolute leak flow in m^3/h is thus much higher for buildings with a higher façade area.

Other parameters have been evaluated, with the following trends (not illustrated here):

- The building orientation has only a small influence on the LIR at building scale. The sensivitiy is however higher for systems with natural supply openings (A and C systems). If natural vents are orientated in front of the dominant wind direction, overflow through these vents leads to higher uncontrolled flow rates (difference of 0.05 in LIR in some cases).
- The terrain roughness has a predicable effect: the higher the roughness (more shielded), the lower is the LIR. The variations are about 0.03 in LIR between terrain categories II and IV.
- Leaks distribution: the impact is not significant when analyzing at building scale.

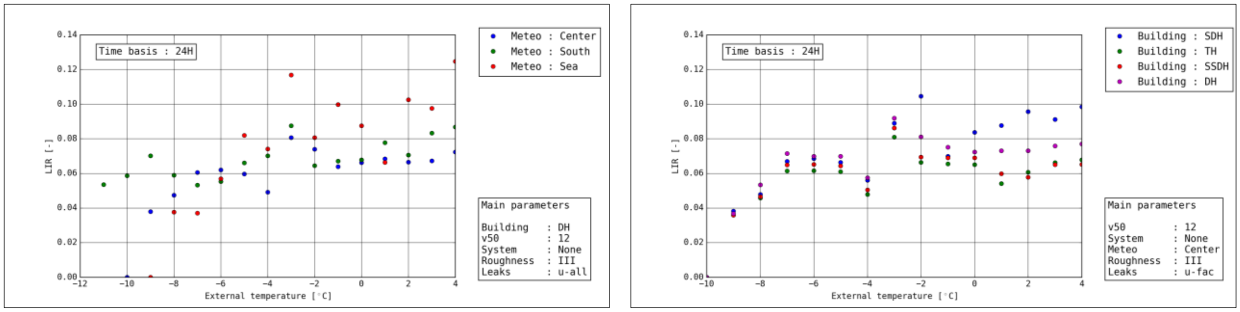

Figure 4 Left plot: LIR as a function of the temperature for 3 weather conditions. LIR are higher at low temperature for the South of the country (combination low temperature and wind more probable), but much higher at Sea for higher temperatures (due to strongest wind). Right plot: Impact of the building. There is little difference in LIR value between the various buildings.

Results at room scale

Results obtained at room scale are illustrated by 4 plots in Figure 5. This figure shows that the room LIR's are much higher than the global buildings LIR, especially if the airtightness is good. Room LIR goes up to 0.5 for low v_{50} and up to 0.3 for high v_{50}. Some higher values were encountered for other (non-illustrated) cases. The two bottom plots show the sensitivity to the leak's distribution, with the different hypotheses presented earlier. The impact of "random leaks" (with the considered distribution, see hypotheses section) on LIR can go up to 0.1 compared to the uniform case.

Overall, wet spaces are more subject to high LIR with C or D systems due to the underpressure induced by extraction fans leading to direct suction of outside air through the building cracks. Also, room LIR are the worst cases for each room and do not necessarily occur at the same time (it is highly dependent on the wind direction). This can thus have an impact on the required heat emission power (room scale), but not on the heat generator power (building scale).

DISCUSSION

The currently applicable standard implicitly considers that the maximum heating demand will occur at the lowest external temperature and that the required heating power for the building is the sum of the required power for the rooms. These two underlying hypotheses are questioned by the outcome of the parameteric analysis.

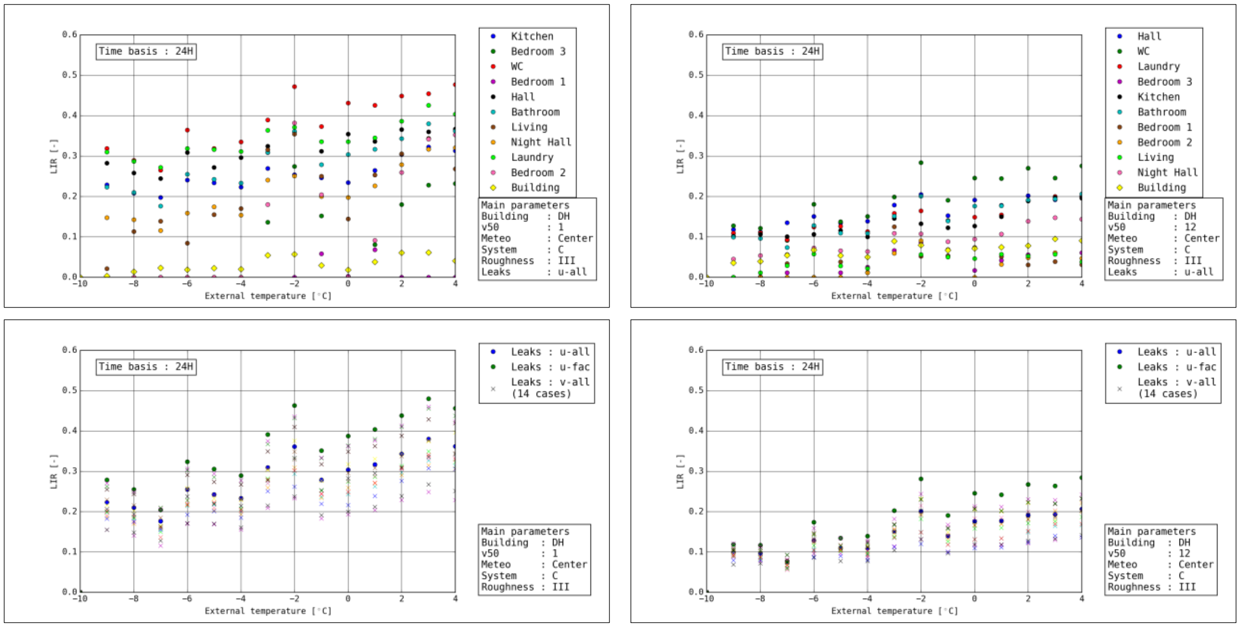

Figure 5 Upper left: LIR per room with good airtightness (v_{50}=1) ; Upper right: LIR per room with bad airtightness (v_{50}=12); Lower left: sensitivity to leak's distribution for bathroom (v_{50}=1); Lower right: sensitivity to leak's distribution for bathroom (v_{50}=12)

1. Considering a typical Belgian climate, the results clearly showed that the LIR (and the infiltration flow rate) is not maximal at the lowest temperatures (design temperatures) but tends to increase with the outside temperature. As a consequence, the heat loss due to infiltration, even after multiplicaton with the temperature difference, may not be maximal for the design temperature. Depending on the other heat losses to be compensated (transmission, ventilation, reheat), the global heat demand of the building (or room) could also be maximum for a higher temperature than the usual one. Using a maximal LIR with the lowest design temperature could lead to an overestimation of the maximum power, while computing only the power at the (supposed) design temperature with the correct LIR may miss the maximum (that could occur at a higher temperature). This may be negligible in a lot of cases, but we expect it to have a non negligible impact in some situations.
2. Room LIR are much higher than building LIR (up to 0.5 in extreme cases, compared to ~0.1 for building). This has for consequence that the sum of all heat emission power (e.g. radiators of all rooms) should be higher than the heat generator power (e.g. boiler).

CONCLUSION AND PERSPECTIVES

This paper raises questions on how the infiltrations are taken into account for the sizing of heating systems of residential buildings. Thanks to multizone airflow simulations, Leak infiltration ratios (LIR) have been computed for hundreds of cases with typical Belgian weather conditions.

The major outcomes are that the maximum expected infiltration flow rate depends on the temperature since the wind intensisty (dominant on infiltration rate) is generally not maximal at usual design temperatures (-7 to -9°C in Belgium). This could have an impact on the calculation of the design heating power in some configurations. It was also highlighted that the design LIR at room scale (power sizing of heat emitters) should be several times higher than the LIR at the building scale, due to some specificities of the ventilation system and simultaneity issues.

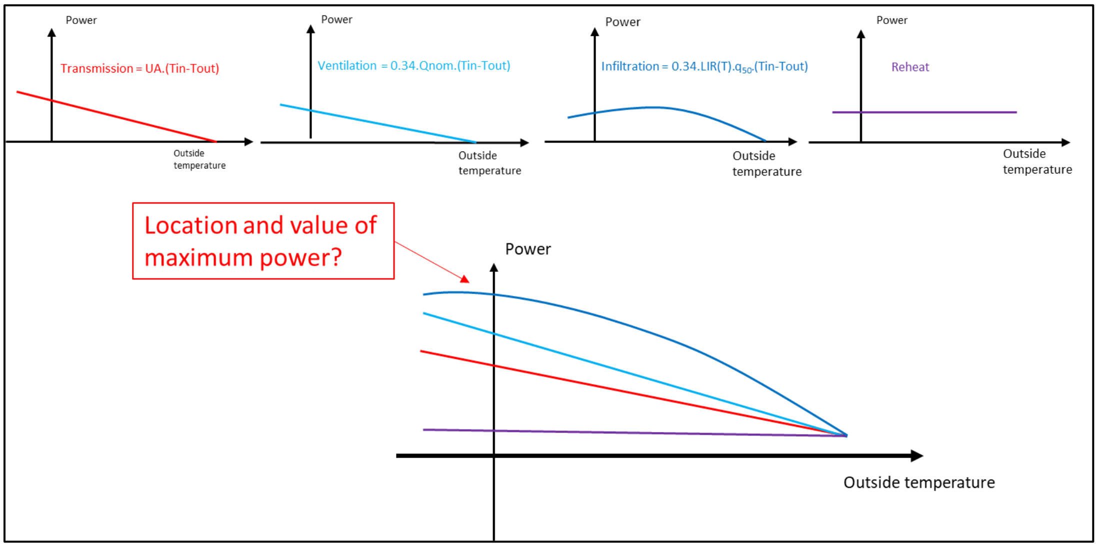

Figure 6 Illustration of the principle for maximum power calculation. The shape and actual value of the curves will depend on the building characteristics (UA, ventilation flow rate, actual v_{50}, etc)

Future work (inside this project and beyond) will focus on:

- Determine in which conditions (UA value, ventilation rate, v50, etc) temperature dependence of the LIR has a significant impact on the design power of heat generators or emitters and if yes, how it could be integrated in future revisions of standards.
- Further exploit the mass of generated data to draw stronger conclusions on the relevant LIR to consider for the individual spaces. This also passes through a better knowledge of true or realistic leaks distribution in a building in the scientific literature, if such literature exists.
- Evaluate the effect of the averaging time (1 or 24 h), compare with annual averages LIR values
- Compare simulations with:
  - tracer gas measurements on real buildings
  - power profiles in dwellings in use

ACKNOWLEDGMENTS

This work has been performed during the Smartpower project, funded by the Belgian Public Federal Service of Economy.

REFERENCES

Dols, W. S., & Polidoro, B. J. (2015). Contam user guide and program documentation version 3.2 (No. Technical Note (NIST TN)-1887).

NBN, D50-001 (1991). Dispositifs de ventilation dans les bâtiments d'habitation. Belgian standard on residential ventilation

NBN EN 12831-1 :2017. Energy performance of buildings - Method for calculation of the design heat load - Part 1: Space heating load; and its Belgian annexe NBN EN 12831-1 ANB:2020

Liddament, M. W., & Agence internationale de l'énergie. Air Infiltration. (1996). A guide to energy efficient ventilation. Coventry: Air Infiltration and Ventilation Centre.

Guyot, G., Ferlay, J., Gonze, E., Woloszyn, M., Planet, P., & Bello, T. (2016). Multizone air leakage measurements and interactions with ventilation flows in low-energy homes. Building and Environment, 107, 52-63.

Jones, B., Persely A., Sherman M., (2016) The Origin and Application of Leakage-Infiltration Ratios