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Influence Of Building Zoning On Annual Energy Demand

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Influence of building zoning on annual energy demand

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ABSTRACT

Simulation tools are widely used to assess the energy consumption of a building. During the modeling process, some choices have to be made by the simulation tool user, such as the division of the building into thermal zones. The aim of this study is to assess the influence of building zoning on the results of the dynamic thermal simulation, including, or not including, airflow and thermal transfers between zones. With this purpose in mind, several different building zonings (49-zone to 11-zone models) are applied to the same office building. The impact of merging the floors is analyzed by considering different roof and floor insulations and the impact of merging the orientations is studied by using different glazed surface ratio and climates. The results of the dynamic thermal simulations are compared in terms of energy demand (heating and cooling) and computational and set-up times.

1. INTRODUCTION

Simulation tools are widely used to assess the energy demand of a building. During the modeling process, some choices have to be made by the simulation tool user, such as the division of the building into thermal zones. The zoning process is user dependent, which results in some difference in energy consumption results and model set-up and computational times. There are currently no studies to generalize zoning methods. However, recommendations were made by USA IBPSA such as grouping zones with the same usage, temperature control, solar gains (separating the perimeter of interior zones without direct sun exposure) and the distribution system type (IBPSA USA, 2012). L. Smith (2012) showed that for complex building shapes, it was not necessary to create a large number of zones. This would increase the complexity of the model without producing more accurate results. Smith (2012) asserts that consumptions are underestimated when the thermal zoning goes against the recommendations listed above (grouping different usages premises within the same floor or orientation). Bleil de Souza & Alsaadani, (2012) tested three different zoning strategies for an office building in London, including a single zone model. The authors suggest a way of zoning by working with window to floor area ration combined with internal gain settings.

Our study focuses on a 4100 m² real office building, spread over 5 floors and built after the 2005 French Thermal Regulations. The building consists of meeting rooms and facade offices in current levels (first to fourth) organized as follows:

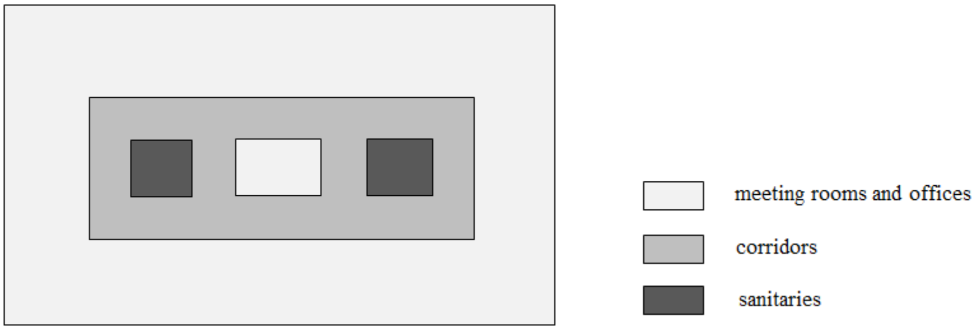

Figure 1: Organization of the current floors of the building

The ground floor is composed of a lobby, front office and a computer room. The top floor has a kitchenette and technical rooms. A central air handling equipped with a recuperative wheel provides the fresh air renewal, which regulates conditions in the offices. The offices are heated or cooled by fan coils whose winter set point is 17 °C by vacancy and 20°C by occupation and whose summer set point is 27 °C by vacancy and 25 ° C by occupancy.

Dynamic thermal simulation was carried out on TRNSYS 17 software. The weather file is generated by Meteonorm (TMY2: Typical Meteorological Year) corresponding to a typical year in Lyon. This type of weather file is appropriate for this kind of study according to Crawley, Huang, & Berkeley (1997). The aim of this work is to assess the influence of zoning on the results of the thermal dynamic simulation including airflow and heat transfer between zones. To estimate the impact of thermal zoning, five cases are studied (from the most to the less complex):

- **49-zone model**: each zone groups the premises with the same air handling system, the same occupancy profile, on each floor and building orientation.
- **44-zone model**: the premises containing the same air handling system are grouped on every floor, even though their occupancy profile is different.
- **26-zone model:** all floors are merged, except for the first and the top floors (under-roof).
- **21-zone model**: the first and the under-roof floors are merged with the others if the premises have the same occupancy profile and handling system.
- **11-zone model:** the premises with a different orientation but with the same occupancy profile and handling system are grouped.

Several phenomena are analyzed:

- **Fusion of floors**: comparison of 21-zone and 26-zone models considering different insulation thicknesses of the ground floor and roof.
- **Orientations grouping**: comparison of 21-zone and 11-zone models for different levels of glazing rate.
- **Airflow transfer between zones**: comparison of 49-zone model with and without considering air transfers from offices to corridors and sanitary.
- **Heat transfer between zones**: comparison of results with and without heat transfer on the 21-zone model.

All comparisons are conducted in terms of annual energy demand.

2. METHODOLOGY AND COMPLEXITY OF MODELS

All models are simplified from the 49-zone model to avoid any differences in settings related to data entry errors. As the set temperatures are identical in all the premises, we built, in addition, a single-zone model started from scratch and without internal walls to assess the error against the considerable time saving.

Model complexity is defined by assessing the risk of errors when creating the model. The main source of error comes from entry parameters - avoided by systematically starting again from the most detailed model -, and errors due to links made in TRNSYS Simulation Studio's interface. This interface requests to interconnect components representing physical phenomena occurring in the building. The more numerous the building zones, the higher the risk of error is. Setup time in Table 1 is estimated starting from scratch and not by simplifying the 49-zone model.

Table 1: model complexity

	Setup time (estimated)	**Number of links (complexity)**	**Computational time (s)**
49-zone model	5 workweeks	787	1573
44-zone model	4,5 workweeks	762	1358
26-zone model	4 workweeks	489	681
21-zone model	3 workweeks	416	563
11-zone model	2 workweeks	246	333
1-zone model	Less than 1 workweeks	113	101

The previous table shows the direct link between setup time, computational time and model complexity. Therefore, it is important to know the impact of thermal zoning on energy demands in order to find a compromise between time and accuracy at the beginning of a study.

3. INFLUENCE OF THERMAL ZONING

Annual heating and cooling demands (MWh) are shown in the following table. The most detailed model, 49-zone model, is taken as a reference for the deviation calculation.

Table 2: Results in annual demand

	Total heating demand (MWh)	**Total cooling demand (MWh)**
49-zone model	87.6	85.3
44-zone model	86.8 (-1%)	86.2 (1%)
26-zone model	86.6 (-1%)	86.4 (1%)
21-zone model	87.4 (0%)	85.8 (1%)
11-zone model	88.7 (1%)	84.1 (-1%)
1-zone model	93.1 (6%)	95.9 (11%)

We can see that, except for the single-zone model, a less detailed zoning of the building does not significantly alter the result. Indeed, the difference between these models is a maximum of 1%. These simplifications provide a negligible difference with the detailed model and it reduces the complexity of the model. The single-zone model provides acceptable results (with a maximum difference of 11% for the cooling demand) in the case of a lack of simulation time to have an order of magnitude of the result, but a 10% error is too high for a detailed study of the building. However, it doesn't provide detailed information such as the energy demand repartition in the building.

The simplification made between 49-zone and 44-zone models consists in grouping the zones with the same handling system, orientation and floor. This is equivalent to grouping corridors and sanitaries. As these zones are not treated, the result does not change.
The following simplification, leading from 44 to 26 zones, is to assemble all the zones of the same handling system and orientation, without floor separation, except for the ground and under-roof floors. The result varies quite a bit.

Unlike the "current floors", the ground and under-roof floors have greater surfaces in contact with the ground and the external environment.

3.1. Floor and roof insulation impact

The following simplification (from 26 to 21 zones) consists in grouping ground and under-roof floors with current floors. As the ground and under-roof floors are directly in contact with the soil temperature and with the external environment, we changed the ground and roof insulations on 26-zone and 21-zone models to understand the influence of the separation of these floors and in particular, why this grouping does not influence the results.

3.1.1. Floor insulation

We tested four thicknesses of floor insulation. This changes the floor heat loss coefficient (U), thus its participation in the total loss of the building (see Table 3). Soil temperature is considered 10 °C in winter and 18 °C in summer. In the reference case (Table 2), floor insulation was 0.12 m.

Table 3: Floor insulation impact on the overall losses of the building

Insulation thicknesses (m)	U floor (W/m². K)	% of the total loss
0.001	3.557	49 %
0.05	0.677	15.8 %
0.12	0.314	8 %
0.3	0.132	3.5 %
0.5	0.080	2.2 %

The histogram below shows the differences in heating and cooling demands between the 26-zone (taken as reference) and the 21-zone models for different thicknesses of ground floor insulation.

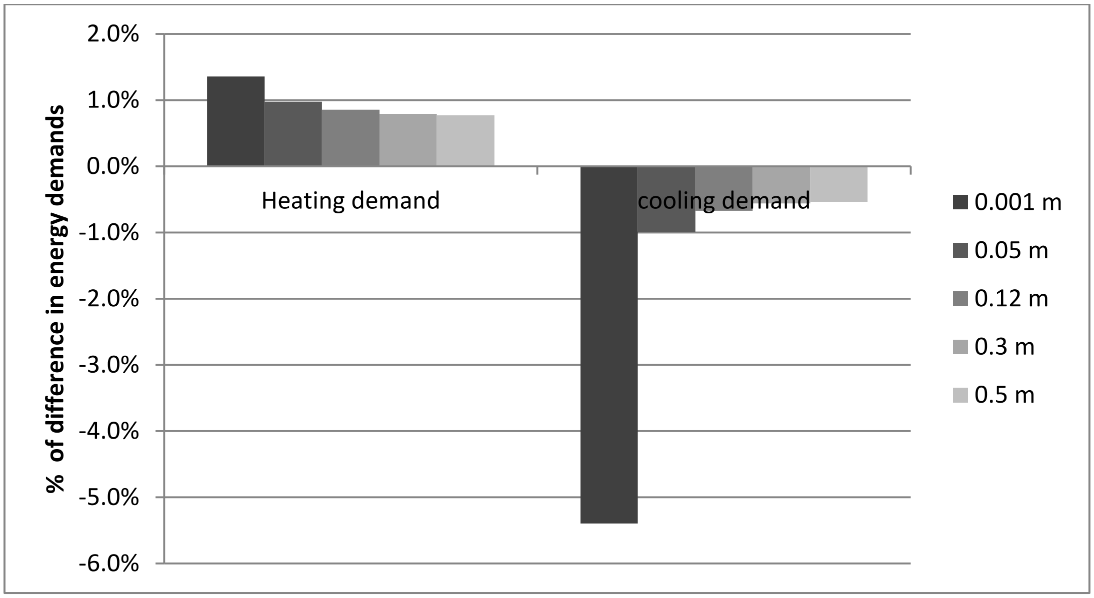

Figure 2: Difference between the 26-zone (reference) and 21-zone models for different floor insulation thickness

The smaller the floor insulation is, the more important the difference is, up to 5.4% for the cooling demand when the insulation is at a minimum, that is to say, participating in 49% of overall heat losses through building walls. However for this case, the differences do not exceed 2 %. For the lowest insulation, if the premises on the ground floor are separated from the currents floors, they will hardly need to be cooled (because of losses to the ground at

18°C). However, if they are grouped with the premises of the current levels, the loss to the soil will be spread over all areas and thus the global cooling demand will be less significant for the model where these zones are assembled. Thus, in the case of a building with floor insulation such that its losses exceed 20 % of the total loss of the building, it is advisable to separate this room from the rest of the building. Otherwise, it is acceptable to combine this floor with the current ones.

3.1.2. Roof insulation

We tested three thicknesses of roof terrace insulation. These modifications of insulation involve a change of the roof participation to the total loss of the building. The actual roof insulation is 0.10 m. The proportion of losses attributable to the roof is contained in the following table:

Table 4: Roof insulation on the overall losses of the building

Insulation thickness (m)	U of the roof (W/m². K)	% of the total heat losses
0.001	3.09	65.3 %
0.05	0.4	19.8 %
0.10	0.216	11.6 %
0.3	0.075	4.4 %

The following figure shows the differences in heating and cooling demands between the 26-zone and the 21-zone models according to different roof insulation thicknesses.

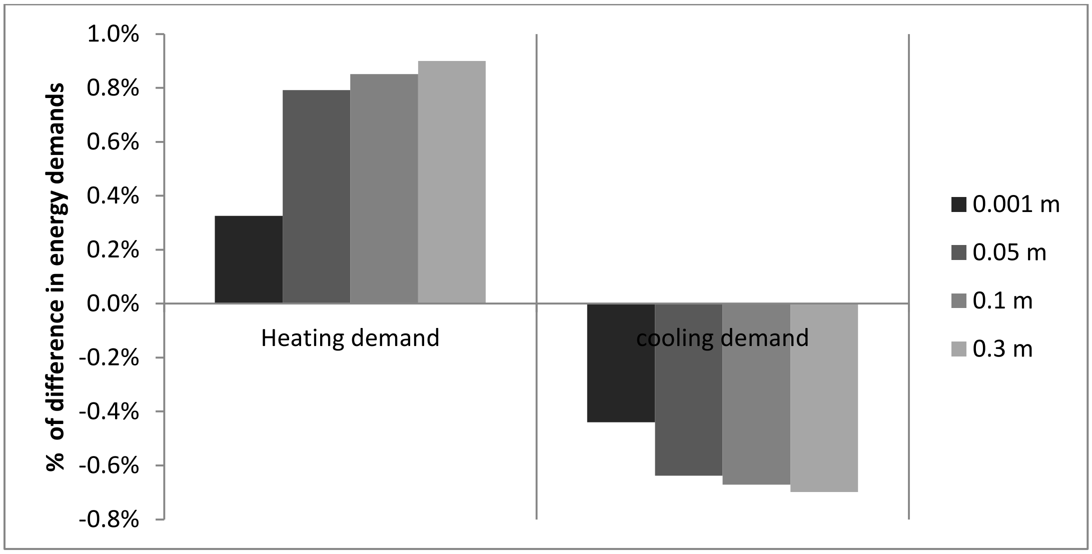

Figure 3: Difference between the 26-zone (reference) and 21-zone models depending on the roof insulation thickness

Under-roof floor separation does not affect the result of energy demands from one model to another (less than 1% difference) even if the insulation is low. The difference found between the demand for the floor and roof insulations is associated with the hypothesis of soil temperature. This is considered to be constant, with a temperature of 18 ° C in summer and 10 ° C in winter, while the roof is exposed to the same stresses as that of the vertical walls of the building. It follows that cooling demands are higher by changing the floor insulation than that of the roof. Given the very wide range of insulation thicknesses, it should be considered that the separation of under-roof floors doesn't change, in our case, the result of demands.

3.2. Glazing rate and climate impacts

The simplification of the model leading from 21 zones to 11 zones consists in grouping premises with the same handling system even if the orientations are different. Thus, to measure the influence of the orientation and therefore, the solar radiation, we modified the glazing rate (that is to say, the total area of glazing compared to the total area of the building). The reference case model has 45% glazing, the loss coefficient of the glass is 1.3 W / m². K and of the opaque walls is 0.36 W / m². K. The increase of the glazing rate thus increases the total demand of the building (the percentage of glazing increases following all orientation), as can be seen into brackets in Table 4 the relative differences in consumption between the 21-zone model (taken as a reference) and the 11-zone model.

Table 5: Total building demand at different glazing rates

Glazing rate	Model	Total heating demand (MWh)	Total cooling demand (MWh)
15%	21-zone	73.8	49.5
	11-zone	75.7 (3 %)	48.2 (-3 %)
45%	21-zone	87.4	85.8
	11-zone	88.7 (2 %)	84.1 (-2 %)
76%	21-zone	100.1	144.3
	11-zone	101.0 (1 %)	140.0 (-3 %)
99%	21-zone	108.2	167.3
	11-zone	108.6 (0 %)	163.5 (-2 %)

Building demand increases significantly in absolute value based on glazing rates, especially in summer when they are multiplied by 3.4 in the 11-zone model - 15% and the 11-zone model - 99%. Nevertheless, the relative differences, plotted in the following figure, appear to remain low between the 11-zone and 21-zone models for each level of glass surface.

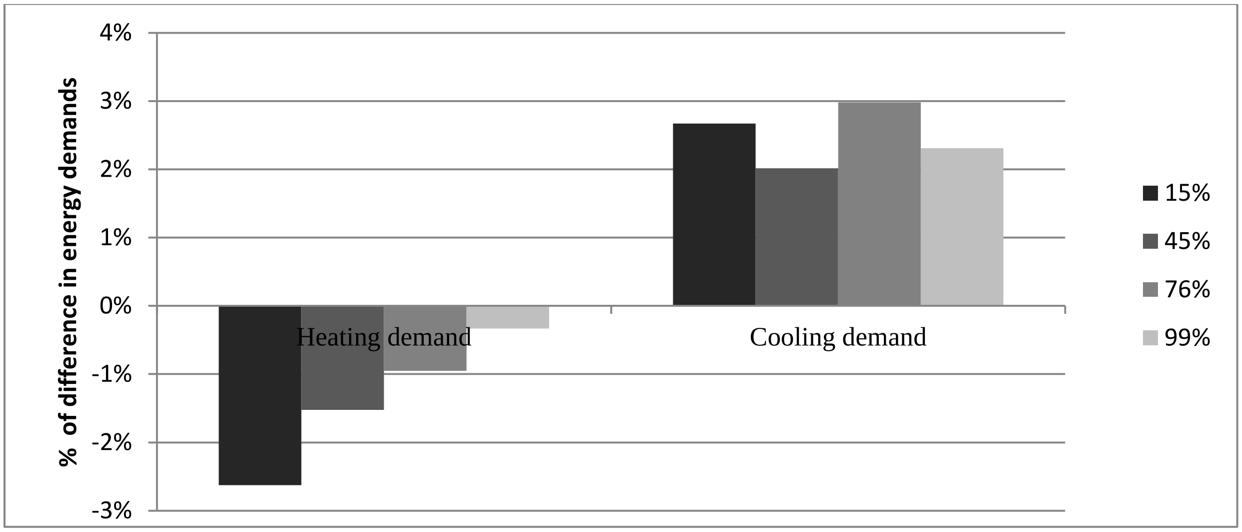

Figure 4: Difference between the 21-zone model (taken as reference) and 11-zone model according to the glazing rate of the building

We can see that grouping of orientations does not lead to any significant difference, whatever the glazing rate is. The difference never exceeds 3% even in the case where the glazing rate is 99%.

To understand if the previous results are due to the climate of Lyon, we tested two different French climates: Strasbourg and Nice climates, with the following characteristics:

Table 6: Climates characteristics

	Strasbourg	Nice	Lyon
Average temperature	9.8°C	15.3°C	11.4
Minimum Temperature	-11.4 °C	1.3°C	-8.8
Maximum temperature	32°C	30.3°C	32.6

Climate changes influence the total demand of the building, as can be seen into brackets in Table 4 the relative differences in consumption between the 21-zone model (taken as a reference) and the 11-zone model. The reference case glazing rate is used (45%) for each climate.

Table 7: Total building demand at different climates

Climate	Model	Total heating demand (MWh)	Total cooling demand (MWh)
Lyon	21-zone	87.4	85.8
	11-zone	88.7 (2 %)	84.1 (-2 %)
Nice	21-zone	19.8	131.8
	11-zone	19.2 (-3 %)	130.5 (-1 %)
Strasbourg	21-zone	120.8	64.3
	11-zone	122.8 (2 %)	62.6 (-3 %)

Building demands vary significantly in absolute value based on climates. Nevertheless, as previously, the relative differences, plotted in the following figure, appear to remain low between the 11-zone and 21-zone models for each climate.

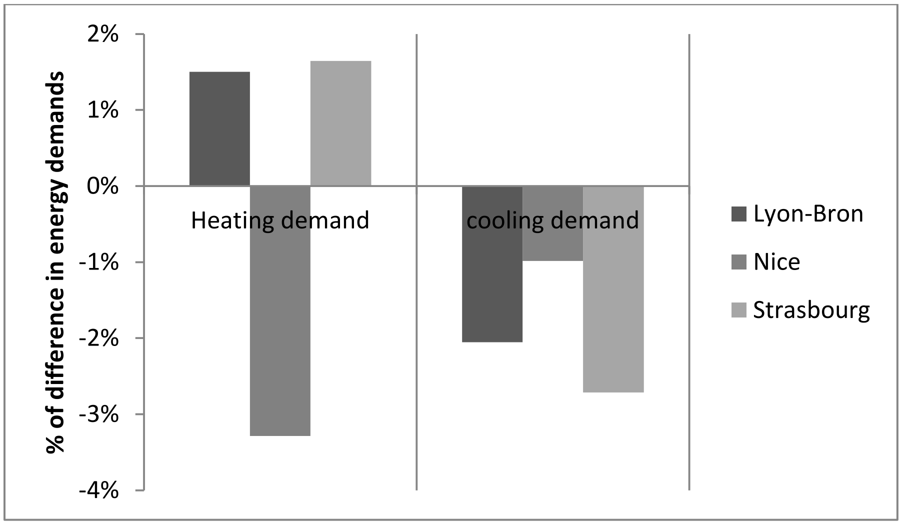

Figure 5: Difference between the 21-zone model (taken as reference) and 11-zone model according to different climates.

However, this result cannot yet be generalized it still requires further analysis. Nevertheless, for this specific building, with this climate, treatment and similar inputs, it is not necessary to separate orientations.

4. IMPACT OF AIRFLOW BETWEEN ZONES

Although air infiltrations have been considered, the previous models do not take into account airflow transfer between zones: The inputs and outputs of the whole building are defined. Taking into account the airflow transfers between zones involves defining coupling flow between offices and corridor (dash arrows) and between corridor and sanitary (thin black arrows), considering the same infiltration as the previous model (figure 6).

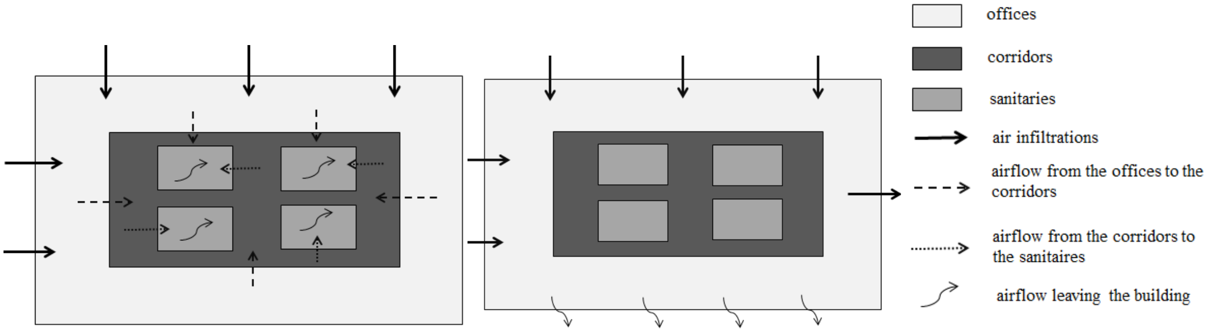

Figure 6: Difference between the model with (left) and without (right) airflow transfers in a floor of the building

Thus, we added these airflow transfers to the 49-zone model. It is observed that the airflow transfers do not affect the result. Indeed, the difference between the two models is 1% in cooling requirements and none for heating. However, the calculation time increases by 14% and the setting time rises too. From a "thermal" point of view, the path of the air inside the building does not affect the result.

5. IMPACT OF HEAT TRANSFER BETWEEN ZONES

5.1. Heat transfer between floors impact

To study the influence of heat transfer between zones, using the 21-zone model, we removed the thermal adjacencies through the current floors. The difference between the models is 3% for heating demand and 0% for cooling demand. The few differences may be due to the removal of heat transfer between heated and unheated areas because this involves only small areas (4% of the total surface).

5.2. Heat transfer between heated zones impact

Still with the 21-zone model, the removal of thermal adjacencies between heated zones does not change the result (0% for heating and cooling demands). It is important to maintain adjacencies between heated and unheated areas. Otherwise, it is possible to allocate internal gains from untreated zones into treated zones (e.g. in proportion to the surface), which would take more time than simply considering these adjacencies. Indeed, if the internal gains of untreated zones were not displaced, this would cause overheating in the untreated areas that could not cool because they are not thermally connected to the surrounding areas. Figure 7 shows the heat transfer between the zones in the case of consideration of adjacencies. Then, the second figure shows the non-treated areas with a continuously increasing temperature.

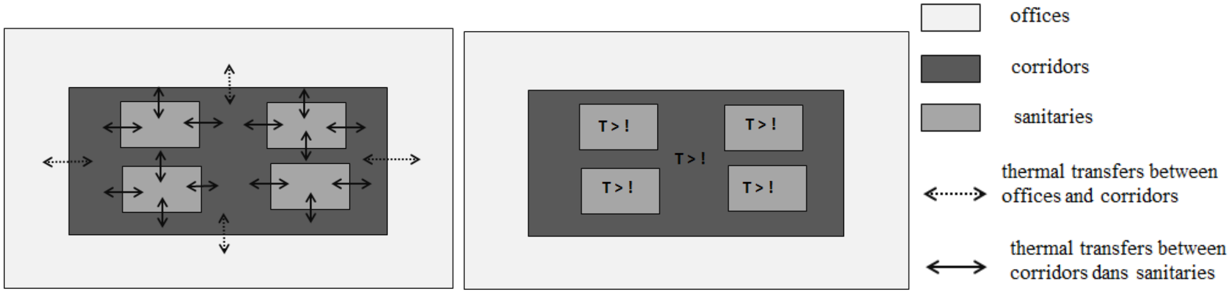

Figure 7: Difference between the model with (left) and without (right) heat transfers in a floor of the building

6. CONCLUSION

This study demonstrates that in the case of an office building in French climates, it is not necessary to separate the current floors of the ground and under-roof floors when the loss of these zones are less than 20% of total losses. Moreover, the separation of zones by orientations even for important glazing rates is not required, the difference being 1%. Thus, it is possible for such a building to reduce the setup time by 2.5 to 3 times because there are less connections to carry out. The time of calculation is divided by 5. If a quick assessment of the building consumption is necessary and all the premises have the same set temperature, a single zone model could be acceptable but not accurate. This result should be facing other buildings to establish more generalizable zoning strategies.

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