Energy environmental monitoring in historical buildings; a simplified methodology for modeling realistic retrofitting scenarios. The case study of Schoonsehof Kasteel in Antwerp (Belgium)

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1. Introduction
During the past years, in the frame of the energy environmental policies, Europe assisted to an increased development of measures aimed to reduce energy consumption in existing buildings stock, as urged by the EPB Directives [European Union, 2003; European Union, 2010]. Despite general derogations for officially protected buildings quoted in art 4 EPBD, these interventions, are rising also in historical buildings.

According to a recent study made by Building Performance Institute of Europe, the entire European existing building stock will be totally refurbished in order to achieve Energy and CO2 reduction by 2050. According to the study, minor and moderate interventions could be performed in case of heritage buildings [BPIE, 2011].

In the daily practice, historical buildings are mostly considered as existing buildings, therefore, when they are going to be renovated, a solely analytical assessment is preferred to a systemic and interdisciplinary more aware approach [P. M. Davoli, 2010]. The renovation strategies proposed after a solely analytical assessment might be not complete since several technical and architectural characteristics are not surveyed. Therefore a preliminary “in situ” monitoring aimed at energy environmental and material evaluation, should be considered as support for decision makers.

It is well known that the influence of surrounding environment on Indoor Thermal Quality (ITQ) in historical buildings is higher than for new and existing buildings. Catin [R. Cantin, J. Burgholzer, G. Guerracino, B. Moujalled, S. Tamelikecht, B. G. Royet, 2010] has quantified the relation between historical dwellings thermal behavior and the surrounding environmental indexes. A correlation of 60% between external and internal physical indexes was found in historical buildings compared to 10% of correlation in modern dwellings.

Historical buildings were designed on a basis of an eco-systemic interaction between building and outdoor environment: “permeable system”; while modern buildings have been designed as closed hygrothermal environment, therefore equipped with HVAC system. The strong relation between (historical) building and environment could be unavoidable [M. La Gennusa, G. Rizzo, G. Scaccianoce, F. Nicoletti, 2005] even though the building has been equipped with HVAC system. The Indoor Thermal Quality (ITQ) assessment, is fundamental for the energy classification since energy consumptions are directly affected by indoor thermal conditions. Dissatisfied building users might change independently the thermal conditions, and this has a direct implication on energy consumption [S. P. Corgnati, E. Fabrizio, M. Filippi, 2008].

This paper presents a simplified assessment methodology for historical buildings by taking into account environmental, energy and architectural aspects. As a case study, a public historic building in Antwerp (Be) is presented.
2. Schoonselhof Kasteel: Building characteristics
Schoonselhof Kasteel is a public standing alone building situated on a island surrounded by an artificial water basin and a big suburban park in Antwerp. The building is composed by four floors, one of them basement. Only ground floor and first floor are partially used as offices.
The discontinuous use of the building over the time, has leaded to a distributed material deterioration. The thermal losses “building- environments” are coupled with huge thermal losses “building- building” since attic and basement levels are unheated. The predominant building technologies are: brick and mortar for masonries (with different thickness), timber ceiling for the first - second floor and roof (with different thickness), brick and mortar vaults between the basement and ground floor.

2.1. In situ monitoring, Methodology
The building monitoring was aimed to assess: building consumptions, thermal behavior, indoor comfort, exploitable building peculiarities for retrofitting scenarios. The periods were selected in order to cover the whole year. Fifteen days for winter configuration: 20/02 till 07/03 2013, and one month: 07/06 till 07/07 2013 for spring and summer assessment. Another investigation will be performed during autumn.
In order to get an accurate patch of thermal distribution across different building parts, key rooms for each floor were selected. In the building were placed 26 data loggers for relative humidity and temperature continuous monitoring. The survey was also aimed to measure light intensity and CO2 concentrations in the offices. This results are not discussed in this paper.
Although physical indexes have been logged each 10 minutes for the whole day, the indoor comfort has been evaluated during the working hours (8,00 am- 4,00 pm). In the rest of time the building is unused. During the monitoring campaign, infrared inspections and blowerdoor tests were performed in order to figure out material heterogeneities, thermal proprieties and to get the current building air leakages curve.

3. Thermal energy consumptions
During the winter monitoring period, thermal energy consumptions were cal-
culated from the boiler monitoring data. An ultrasonic flow meter was used in order to monitor the flow rate and the temperature from and to the boiler. The gas consumptions and the heat loss were normalized for the whole heating season by using the degree days methodology. For the entire monitored period the heat power delivered by the boiler was 14 115.57 Kwh. Consumptions related only to the building heating, since in the whole building there is not DHW. On basis of this simplified methodology, the building annual thermal consumption has been quantified in 151 751.97 Kwh. An annual gas consumption of 15.134 m³. This consumption is not commensurate with a high indoor thermal comfort.

4. Indoor thermal quality (ITQ)
The enhancement of indoor air quality (IAQ) has not solely an impact on energy consumption, but it has an effect on people productivity [I. Sarbu, C. Sebarchievici, 2013], optimal conditions for exhibitions [S. P. Corgnati, V. Fabi, M. Filippi, 2009] and people comfort. The EN 15251/2008 [CEN, 2006], intro-
duced a methodology for a whole indoor climate evaluation and classification in both: building projects (design rating) and existing building (operational rating). The indoor thermal quality labeling approach was already considered by EN 7730 2005 [CEN, 2005].

The classification of thermal comfort in totally mechanically controlled indoor environments, is provided on the basis of Predicted Mean Vote (PMV) [Fanger P.O., 1970] and Percentage of Dissatisfied People (PPD).

EN 15251 suggest to base the winter assessment on PMV and PPD for buildings equipped with HVAC; but it introduces a comfort evaluation, for the free running periods, based on the adaptability theory. The proposed methodology is applicable if the building is not equipped with cooling or mechanical ventilation system. Often, historical buildings are not provided of cooling system, but peculiar architectural characteristics (thermal inertia, natural cross ventilation) might be enough to satisfy occupants expectations. The EN 15251, encourages passive solutions in cases of overheating. Solutions that normally should be preferred in historical contexts whereas installations might threat the building architectural character [A. Maahsen-Milan, K. Fabbri, 2013]. The standard considers the importance of adaptive user behaviors and the strong link between indoor thermal comfort and outside mean running temperature. According to the standards, a modulation of heating and cooling set points, if based on outside temperature, could generates not only a better indoor thermal comfort, but also a substantial energy consumptions reduction.

4.1. Indoor Thermal quality (ITQ): Methodology

Within this study PMV-PPD (EN 7730) and acceptable operative temperature intervals (EN 15251) have been used to classify ITQ in heated and free running periods for the heated levels of the building. Outside from the heating season, the acceptable temperature indoor limits have been calculated by using 3 equations based on the running mean outdoor temperature. The equations give the upper and lower indoor operative temperature limits for buildings not mechanically cooled or ventilated for three indoor categories (see table 4.1.1). In order to understand the long term performance for each room, Performance Index and Failures Indexes and relative deviations have been calculated for heated and free running period. The indexes are an important analytical support to have an immediate data interpretation. By using them, it’s possible to assess the discomfort causes and the reasons for each room classification. Finally the performance categories reached during winter (based on PMV scale) have been compared (see Table 4.3) to those reached during summer, in order to evaluate the thermal comfort during the whole year.

-Performance Index (%) it represents the percentage, in time, in which the monitored parameters are in the acceptable interval (≥95% EN 15251 requirement).

\[ \text{Pl} (\%) = \sum_{t}^{\infty} \left( \frac{t \text{ interval limits}}{\sum_{0}^{t} \text{total time}} \right) \]

<table>
<thead>
<tr>
<th>COSTANT</th>
<th>CATEGORY I</th>
<th>CATEGORY II</th>
<th>CATEGORY III</th>
</tr>
</thead>
<tbody>
<tr>
<td>UPPER LIMIT</td>
<td>$0.33 \text{in} \text{m}+18.8\ldots$</td>
<td>+2</td>
<td>+3</td>
</tr>
<tr>
<td>LOWER LIMIT</td>
<td>$0.33 \text{in} \text{m}+18.8\ldots$</td>
<td>-2</td>
<td>-3</td>
</tr>
</tbody>
</table>

Long Table 4.1. 1 limit values of Indoor operative temperature; EN 15251

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- Failure Index (%) it represents the percentage, in time, in which the monitored parameters are out from the acceptable interval (≤5% EN 15251 requirement).

\[ FI(\%) = 1 - PI \]

- Failure Cold Index (%) it represents the percentage, in time, in which the monitored parameters are below the lower acceptable limit.

\[ FLc(\%) = \frac{\sum_{t}^{t} (t \text{ below lower limit})}{\sum_{0}^{t} (\text{total time})} \]

- Failure Warm Index (%) it represents the percentage, in time, in which the monitored parameters are above the upper acceptable limit.

\[ FLw(\%) = \frac{\sum_{t}^{t} (t \text{ above upper limit})}{\sum_{0}^{t} (\text{total time})} \]

4.2. Free running period (EN 15251.2008): Results discussion

The general allowable indoor operative temperatures, for the entire free running period (table 4.1.1), have been calculated for each category, against the exponentially weighted running mean of the daily outdoor temperatures and they were plotted for the whole monitoring period (see table 4.2.1)

\[ \theta_{rm} = (1 - a) (\theta_{ed} - 1 + a \theta_{ed} - 2 + a^2 \theta_{ed} - 3 + ...) \]

\[ \theta_{rm-1} = \text{Running mean temperature for previous day} \]

<table>
<thead>
<tr>
<th>Date</th>
<th>Acceptable indoor operative temperature intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>30/06/13</td>
<td>CAT 3 UPP LIMIT</td>
</tr>
<tr>
<td>15/06/13</td>
<td>CAT 2 UPP LIMIT</td>
</tr>
<tr>
<td>28/06/13</td>
<td>CAT 1 UPP LIMIT</td>
</tr>
</tbody>
</table>

The indoor operative temperature methodology is suggested for office buildings where occupants are involved mainly in sedentary activities (1,2 met). This is the case of Schoonselhof Kasteel. During the monitoring periods the mean radiant temperature (calculated as weighted average of surface temperatures in rooms) showed temperature differences below 4°C compared to Indoor temperatures, while room air velocity was below 0,10 m/s. Therefore air temperature has been assumed as expression of operative temperature.
and mean radiant temperature\(^2\). The indoor thermal quality classification according to EN15251 for spring-summer monitoring (each room ground and first floor) is represented in a chromatic scale as explained in Image 4.2.1.

No rooms in the whole building are in compliance with the limits imposed by the first category. Ground and first floor are classified between the second and the fourth category. Attic level is entirely classified in third category and basement level in the fourth one. From the long term indexes is possible to understand the category results. Flc (%) and Flw (%) for each room in both the levels are plotted against the limits of the second category.

The rooms not classified in second category are: 0.00, 0.06, 0.07.08. All of them show high frequency of Failure cold Index (Fic). The monitored temperatures were lower than the lowest threshold allowed by the category, for 95% of time. These rooms are: main entrance (0.06), connective space (0,00) and archive (0.07.08). Normally the coldest rooms within this floor.

In the first floor, rooms: 1.05,1.07,1.14 reached the indoor requirements imposed by the second category for less than 95% of time. Therefore all of them have been classified in 3rd and 4th category.

In rooms 1.05 and 1.07 (A), up to 16,12% of monitored temperatures, for more than 95% of time, were above the allowed upper limit. In this case, the thermal discomfort is related to overheating. In room 1.14 (B) although the discomfort occurred for both the conditions: too cool and too warm, the highest deviation frequency is related to the Cold Failure Index (Fic). Indeed the 4,78% of measured temperatures, for 95% of monitored time, were below the lower threshold limit.

### 4.3. Heating period (EN 7730.2005). Results Discussion

In winter, PMV and related PPD for each rooms were calculated. For 95% of monitored time, four rooms at ground floor have been in compliance with the third category requirements, while three other rooms in the same level and all

![First floor PI - FI (cat II)](image)

Table 4.2 3 PI (%) Fic(%) Flw (%) among second category, first floor, free running period
the rooms at first level, weren’t in compliance with the first three categories. Thus, these rooms and the whole first level were classified in fourth category. All the rooms in both the floors are equipped with thermostats on each radiator. The users were allow to adjust the room temperature according to their needs. Only room 1.07 was unheated.

As a confirm of the free running thermal path, the coldest rooms at the ground floor for the winter period are: 0.00, 0.06, 0.07.08. The heating system contribution, in these rooms, is not enough to ensure a classification within the first three categories. In 0.06 and 0.07.08 several envelope critical aspects (not described for brevity) were detected: heat losses and heterogeneous temperature distributions, occurred in both opaque and transparent components. The defects in the envelope combined with a scant contribution from the heating system and direct solar gains caused very low indoor temperature. The PMV lower limit was below the lower threshold for second and third category. Therefore these rooms were classified in fourth category.

In the offices (0.01 and 0.03) the combination of solar gains together with

Table 4.3 1 PI (%) Fic(%) Fiw (%) among second category, ground floor, heated period

Table 4.3 2 PI (%) Fic(%) Fiw (%) among second category, First floor, heated period
heating contribution, have been cause of overheating. The too warm temperatures have been up to 20.45% for the 95% of monitored time. Due to this discomfort, the two rooms can’t be classified at second category. In the first floor long the southern façade, the solar gains and heating system combination caused a slightly permanence of monitored temperatures above the maximum limits allowed by the second category. But except room 1.05, the Cold Failure Index frequency shows higher percentage of deviations. Up to 88.74% of measured temperatures have been below the lower heating threshold for 95% of time. This is the reason why the rooms at the first floor weren’t classified at second and third category. At first level, because of the heating system and building envelope ineffectiveness, the ITQ is strongly weak. Despite this poor indoor thermal performance, the heat consumption is rather high.

5. Conclusion
This study shows a typical configuration findable in a large amount of historical buildings equipped with obsolete heating system. The monitored Indoor Thermal Quality highlights better results in free running period without any installations, than during the heated period. When the heating system is on, despite the high gas consumptions, the building has impressively low ITQ. Mostly due to extremely low indoor temperatures. The heating system ineffectiveness and envelope failures, have caused also local discomforts: chain effects. Indeed the low indoor temperature has led the users at adjusting manually the radiators temperature, causing overheating because of the combined heating and solar gains contributions. During the free running period, Schoonselhof Kasteel had a better ITQ. The building has shown indoor temperatures rather cool at ground floor and slightly warm at first floor, but always in compliance with more performing categories. The low percentage of deviations, especially related to overheating, might be reasonable solved by exploiting passive solutions as suggested by EN 15251.

The proposed, ongoing, study is a simplified but complete approach aimed at evaluating the building in its several subsystems: Indoor comfort, plant system effectiveness, material conservation, building thermal behavior, energy consumption. The results of this study are useful not only for a more accurate building modeling, but also to address more aware retrofitting scenarios. Any retrofitting is aimed to a thermal environmental improvement, but it always leads to a physical building modification. Therefore a building preliminary monitoring might be a solution (especially for historical buildings), in order to find feasible retrofitting solutions, taking into account the real building behavior, and exploiting its peculiarities by designing passive solutions as first option in order to improve thermal quality and energy efficiency.

Notes
1 Exponentially weighted running mean of the daily outdoor temperature, 3.12 in EN 15251.2008.
2 Recommended criteria for the thermal environment, Annex A in EN 15251.2008.
References
BPIE: Building Performance Institute of Europe, 2011, Europe’s buildings under the microscope.
P. M. Davoli, 2010, Il recupero energetico ambientale del costruito, Maggioli.