# Influence of the degradation of building components on thermal comfort

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## ABSTRACT

This paper presents results of an ongoing research conducted at the BEST–Polytechnic of Milan about the correlation between the over time degradation of building envelop components and the indoor climate. There are many studies in literature about the degradation over time of various characteristics or properties of materials and components used in building envelops but none of these assess the influence of this degradation on the indoor climate (i.e. minimum temperature in the winter conditions, maximum temperature in summer conditions, etc.) or on the indoor climate calculations that can be done using international or local standards.

The research, focused on external vertical walls, started from the study of how the envelope of buildings works, highlighting five major contributions on the indoor climate quality.

We called these five contributions '*essential requirements*' of building envelope components and started to analyse how the degradation of the materials constituting the building envelope influences the performances supplied by the building components and how the changing of the performances of building components affects the thermal comfort.

The second phase of the research, starting from indoor climate conditions stated by Italian laws (i.e. the indoor air temperature during winter), has been focused on the researching of limits for the degradation of characteristics or properties of materials. This part of the research came out with what we call the '*performance limits*' of building components characteristics, that is to say the boundaries that are not to be passed during the degradation of building components if we want the indoor climate to satisfy standards and laws in Italy.

The last part of the research has been dedicated to a sensitive analysis of the results obtained to: (a) errors that may occur during the design process in estimating initial values and degradations of building materials used; (b) errors that may be present in the modelling of outdoor climate.

## INDEX TERMS

Indoor climate; Essential requirements; Performance limits; Sensitive analysis; Degradation

## INTRODUCTION

There are many studies in literature about the degradation over time of several characteristics or properties of materials and components used in building envelopes, but none of these ones correlates the influence of this degradation with the indoor climate (i.e. minimum temperature in the winter conditions, maximum temperature in summer conditions, etc.) or with the indoor climate calculations that can be done using international or local standards.

This research conducted at the BEST–Polytechnic of Milan, focused on external vertical walls, aims to analyse how the degradation of materials constituting the building envelope influences the technological and environmental performances supplied by the building components, and how the changing of these performances affects the thermal comfort.

Working on indoor climate, this method makes it simpler to correlate the end of the service life of a building with the lack of thermal comfort over time due to the 'performance death' of

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its building components, through the degradation of some characteristics (‘performance characteristics’).

## PERFORMANCE LIMITS METHOD (PLM)

The starting point was the definition of service life found in ISO 15686: “period of time after installation during which a building or its parts meet or exceed the performance requirements”; the main aim was to tie the estimated service life to hygro-thermal performances of buildings.

A brief description of the performance limits method is the following:

- First of all it is necessary to define performance requirements for each part of the building.
  We thought it important to be tied to hygro-thermal performances because these are directly felt by users. On the other hand, this choice bind estimated service life values to hypotheses made on indoor space during the design stage, because some of the computational models used made assumptions on rooms’ dimensions. We used minimum performance requirements stated by Italian laws in the case study.
- Then, performance requirements for each building component must be computed.
  The translation of performance requirements of spaces of the building to performance requirements of building components is quite difficult. Computational model to verify indoor climate parameters lack and are often complex; when possible we used algorithms stated in international standards. During this step minimum values stated by Italian laws for hygro-thermal performance of spaces were translated into minimum values for building components performances.
- The next step is to assign performance tasks to each layer of the component.
  Each minimum value for building components’ performances generates one or more boundary values for characteristics of materials of each layer of building components. If these boundary values are crossed, the component will be no longer able to satisfy user needs. We call these boundary values for the characteristics of each layer of the component ‘*performance limits*’.

### Case Study

As a test application performance limits for three different kind of building envelope components were computed. Examples of results obtained for one of these envelope components are presented. A brief description of an external wall is shown in Table 1, where

- $t$ = thickness [m]
- $\lambda$ = thermal conductivity [W/m°C]
- $\gamma$ = density [kg/m$^3$]
- $s$ = specific heat [kJ/kg°C]
- $\mu$ = water vapour permeability [−]

**Table 1** Description of the external timber cladding walls

| Layer | $t$ [m] | $\lambda$ [W/m°C] | $\gamma$ [kg/m$^3$] | $s$ [kJ/kg°C] | $\mu$ [−] |
|---|---|---|---|---|---|
| Internal plaster | 0.015 | 0.9 | 1800 | 0.91 | 35 |
| Lightweight cement-based brickwork | 0.2 | 0.198 | 950 | 0.88 | 6 |
| Thermal Insulation | 0.06 | 0.035 | 50 | 1.25 | 120 |
| External timber cladding—red fir | 0.017 | 0.13 | 450 | 4.97 | 100 |

Table 2 shows most important requirements to building envelope components, which we call these essential requirement, and characteristics of materials that influence their behaviour in relation to the indoor climate.

**Table 2** Essential requirements and performance characteristics of building envelope components

| Ref | Essential requirements | Performance characteristics |
|---|---|---|
| F1 | Control of surface condensation | Thermal conductivity |
| F2 | Control of interstitial condensation | Thermal conductivity, water vapour permeability |
| F3 | Control of thermal insulation | Thermal conductivity |
| F4 | Control of thermal inertia in winter conditions | Thermal conductivity, specific heat, density |
| F5 | Control of thermal inertia in summer conditions | Thermal conductivity, specific heat, density |

In the following part this paper will focus on thermal insulation and thermal inertia in winter conditions, which are the most demanding requirements in an environmental such as the one in Milan. Performances associated with thermal insulation and thermal inertia can be evaluated only if hypotheses on a room are made, because these performances do not depend only on building components, but they are related to a building space too. We use a standard Italian single bedroom of nine square meters (standard minimum) and 2.7 m high. The room has a window in the centre of one of its four walls of 1.125 $m^2$ (standard minimum) with a 1.10 m high railing (standard minimum).

In this work, the performances related to the thermal insulation were computed using the operative temperature as parameter, whereas the ones related to the thermal inertia in winter conditions using a method created and tested at the BEST–Department of the Polytechnic of Milan (Croce *et al.*, 1999), which allows to compute how the indoor air temperature decreases when the heating system has been turned off (from 9 p.m. to 7 a.m.).

Both the operative temperature (during the day) and the air temperature (during the night) are regulated by the Italian laws: the former must be 18°C and the latter more than 17°C.

**Sensitivity Analysis**

First of all a sensitivity analysis of the model was made in order to gain information on how every parameter of the model influences the results. The value of each input characteristic (material, climate and space) was changed by +20% and performances related to essential requirements were computed. Then the same calculation was made with a –20% change and the difference between the two values of each performance was computed, the bigger this difference is the more the characteristic influence performance limits.

An example of results obtained from sensitivity analysis is shown in Figure 1; it shows material characteristics and hypotheses on climate influencing thermal inertia in winter conditions for the external wall used as an example in this paper. Characteristics are ranked from the most influencing (top) to the less influencing (bottom).

Results coming out from sensitivity analysis were summarized in a table, where the influence of every performance characteristics of the component on the computational model adopted is highlighted.

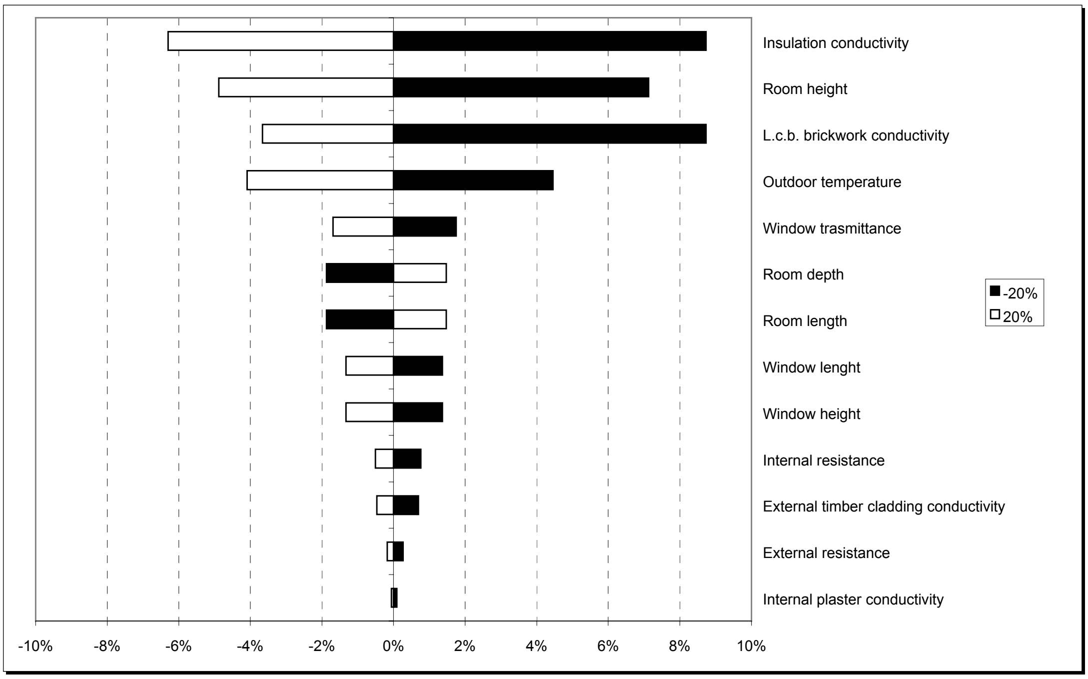


**Figure 1** Control of thermal inertia in winter conditions (F4)—influence of performance characteristics.

## RESULTS

When sensitivity analysis was completed and the computational model was well known and tested, performance limits for every performance characteristics have been estimated starting from the computation of the 'design value' of each performances requirements of building component.

Computing the design value of performance requirements means translating performance requirements of spaces of the building to performance requirements of building components.

For the F3 requirement (control of thermal insulation) 19.6°C is the design value of the operative temperature computed inside the room, whereas for the F4 requirement (control of thermal inertia in winter conditions) 14.2 h is the design value of the time needed to reach an indoor air temperature of 17°C after the turning off of the healing system.

After this first step of computing the design value of the performance requirements of building components, the performance limits for each layer of the external wall object of this paper have been computed. As an example, Figure 2 shows the performance limit for thermal conductivity related to the considered building component.

On the *x*-axis the conductivity increase as regards the design value (so the $\lambda_n = \lambda/\lambda_d$ index is dimensionless) is shown, whereas on the *y*-axis the time needed (after the healing system is turned off) before the indoor air temperature reaches the limit value of 17°C.

As to be expected after the sensitivity analysis, only the insulation layer (through a considerable $\lambda$-increase) is able to drive the building component towards a 'performance fall' such as to compromise the essential requirement F4.

### Risk Analysis

In order to gain information on the influence of errors during different stages of the building process on building performance calculations a risk analysis was performed. A probability function with a triangle distribution (maximum error ±10%) was given to every value of the technical characteristics and a Monte Carlo simulation was performed on both external walls under test.

As comparison with the external wall fully described in Table 1, a typical Italian masonry, made of internal hollow brick, thermal insulating layer and external perforated bricks coated on both side with plaster and finished with water paint was chosen.

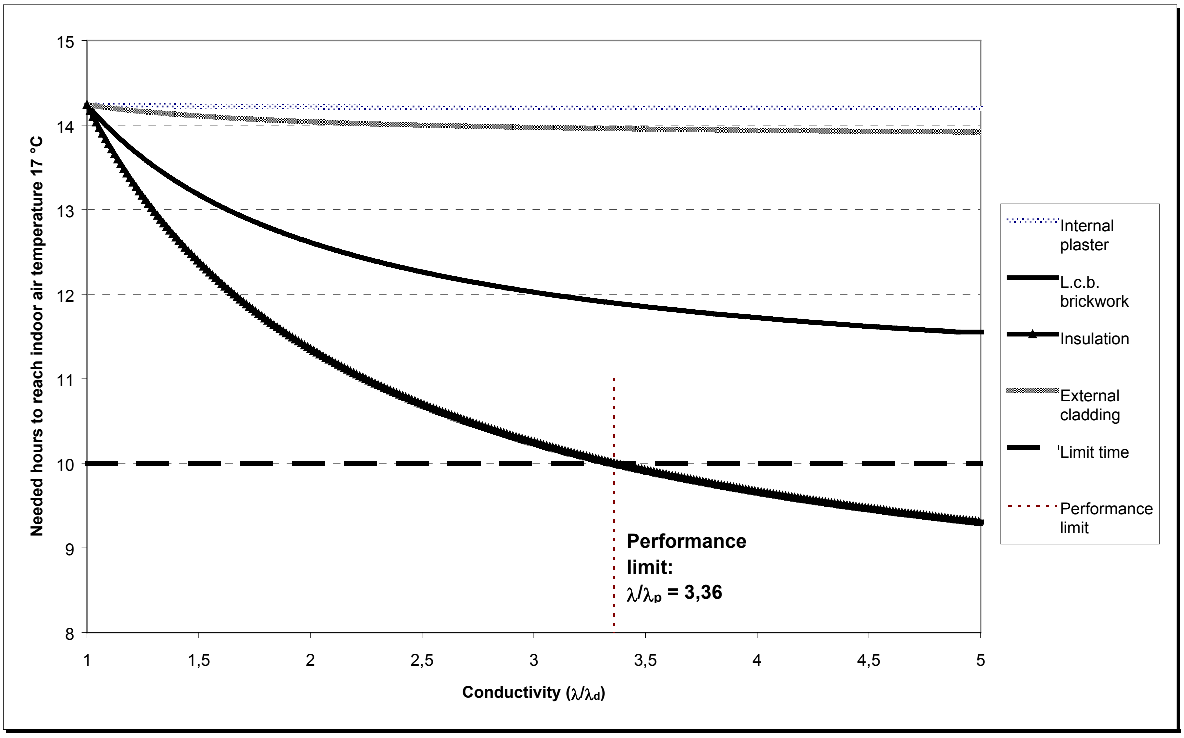


**Figure 2** F4-performance limit reached by the insulation layer for $\lambda_n = \lambda/\lambda_d = 3.36$.

The aim of the Monte Carlo simulation is to measure the probability that the actual indoor climate will differ from the calculated one because of error in the design stage (choosing wrong values for material and climate characteristics) or the construction stage (choosing wrong values for the space characteristics). Figure 3, obtained with 5000 Monte Carlo simulations, shows the probability of a difference between the actual air temperature decreasing during winter night and the calculated one for both of the components of this test application (using the same space and climate conditions). It is important to notice how component 1 is less influenced by errors then component 2 (broken line). But the graph below shows something more; if on the one hand the continuous line shows a bigger accuracy between theoretical results and the reality, on the other hand the external timber cladding wall (left—shifted as regards the deviation from the design value) shows as the errors do not cancel each other out. Taking into account this last remark, the designer might prefer equally the second one.

## CONCLUSION AND IMPLICATIONS

The most important results obtained are:

- the validation of a method for assessing the influence of material characteristics degradation on indoor climate calculations;

- a ranking of the most influencing characteristics (sensitivity analysis). These will have to be strictly controlled in the design stage;
- an evaluation of the risk of unsuccessful indoor climate condition due to error in the different stage of the building process (risk analysis).

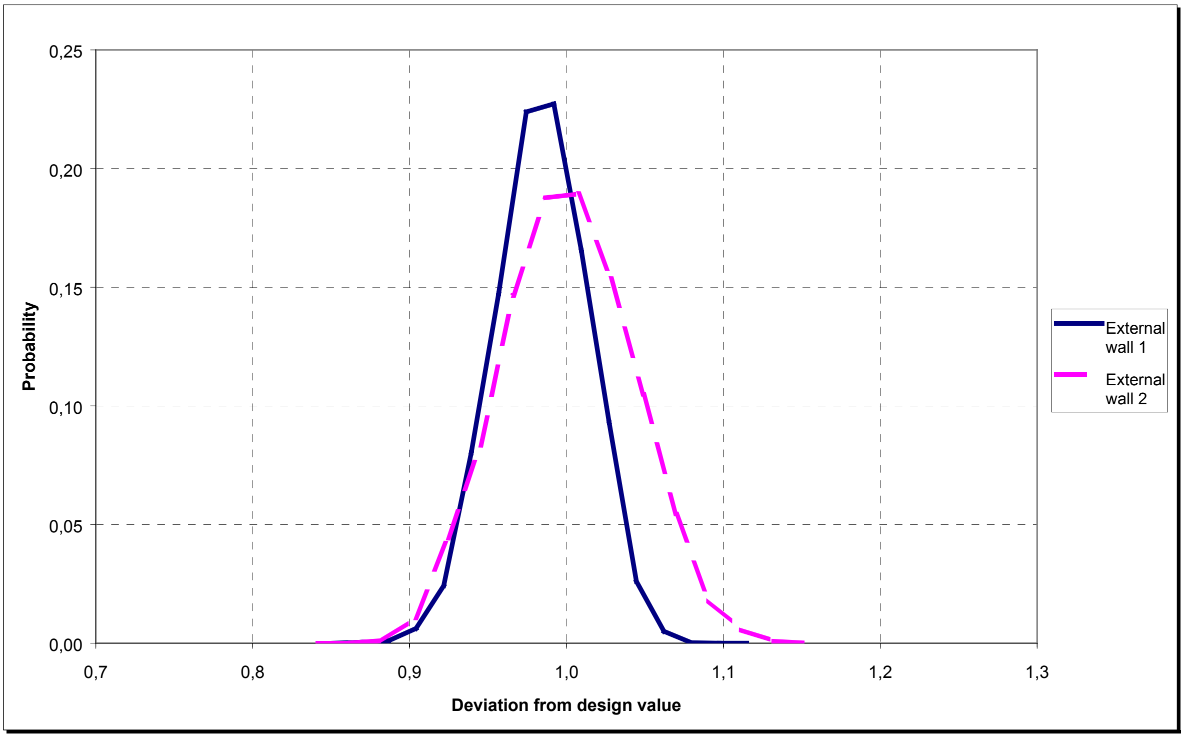


**Figure 3** Risk analysis—comparison between two building components.

## REFERENCES


CEN (1999). PrEN ISO 13788, Hygrothermal performance of building components and building elements—Estimation of internal surface temperature to avoid critical surface humidity and assessment of the risk of interstitial condensation.

Croce, S., De Angelis, E., Filiberti, A. and Sartoretti, P. (1999). La valutazione del comfort termico in condizioni di impianto intermittente. Un metodo di calcolo semplificato. *Proceedings of 'Giornata di studio Giovanni De Giorgio'*, Esculapio, Bologna.

Maggi, P.N., Rejna, M. and Ravetta, F. (1998). Functional analysis as a method to design new building components. *Proceedings of the CIB World Building Congress*, Vol. 1, pp. 333–340.

Re Cecconi, F. (2000). Influence of the degradation of building components on indoor climate calculations. *Proceedings of Healthy Buildings 2000*, Espoo, Finland.

Re Cecconi, F. (2002). Performances lead the way to service life prediction. *Proceedings of 9thDBMC*, Brisbane.