7th International Building Physics Conference

IBPC2018

Proceedings

SYRACUSE, NY, USA

September 23 - 26, 2018

Healthy, Intelligent and Resilient
Buildings and Urban Environments

ibpc2018.org │ #ibpc2018

A framework for comfort assessment in buildings and districts retrofit process

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ABSTRACT

The retrofit design of buildings and districts cannot exclude the occupants' perspective if comfortable and healthy conditions have to be obtained. For this reason, the NewTREND[1] project developed a collaborative platform for the energy efficient buildings and districts retrofit that includes the users' perspective. Three modules have been developed for thermal comfort, acoustic comfort and behavioural assessment. These modules are integrated into a Simulation and Design Hub that, after gathering data from on-site measurements, builds a simulation model of the district, calculates yearly results and exposes them to the design team through a dedicated District Information Model server and user interfaces. These modules perform deep investigations on the occupants' sensation and behaviour, based on both measured and simulated datasets and provide comparisons of comfort performances, considering different retrofit scenarios and related uncertainties. In details, the thermal comfort module performs analysis according to both predictive and adaptive models, evaluates the variability around the design conditions together with sensitivity analysis that highlights which parameters are the most critical for the retrofit design. The acoustic module provides a complete tool to predict and assess the indoor acoustic comfort, taking into account the performance of building envelope and the impact of district noise. Finally, the behavioural module empowers the building energy simulation with co-simulation capabilities that reproduces the real occupants' behaviours in relation to comfort conditions. The final goal of the framework is to support the decision-making process in selecting the optimal retrofit option that achieves the targeted energy efficiency without infringing the occupant's expectation in terms of comfort and well-being.

KEYWORDS

Thermal Comfort, Acoustic Comfort, Behavioural Modelling, Monitoring, Simulation.

INTRODUCTION

Buildings have the main goal of providing comfortable conditions for the occupants. The lower is the comfort sensation the higher will be the probability that occupants occur in non-efficient behaviours and low productivity because of the degraded well-being. Thus, maintaining the optimal thermal conditions in all occupied spaces is a key feature. On the other side buildings account for the 40% of the total energy consumption and they have to become as much efficient as possible so to use the minimum energy to provide comfortable conditions. Considering that, more than the 35% of European buildings have been built before the 60's and more than the 80% before the 90's (BPIE, 2011), they do not include materials and technologies capable of high performance or they have degraded with. In this context, the renovation and retrofit interventions are to be considered as priority to achieve the objective

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[1] http://newtrend-project.eu/

of reducing the global energy consumption and striving to the resilience required for facing climate changes. Comfort plays an important role in buildings renovation. In fact, the recent report "Feel Good, Live Well - The UK home, health and wellbeing report"[2] points out that over 95% of homeowners and renters make some effort to look after their health and wellbeing and health and wellbeing issues in their existing homes they would like to change are in the first position. In this context, the NewTREND project proposes a Collaborative Design Platform to enable wide retrofit actions of buildings and districts, including comfort and well-being into the multicriteria assessment framework. This paper presents the platform and three tools dedicated investigate the occupants' perspective.

METHODS
The NewTREND cloud platform
The main aim of the NewTREND cloud-based platform is to support the collaborative design and to promote the dialogue between the different subjects involved in a retrofit project. In this perspective, a District Information Model (DIM) server has been developed to store data and to make them available for the designers. In parallel, a Simulation & Design Hub (SDH), creating a simulation model of the district, allows effective comparisons between retrofit options at both building and district level and guide the decision makers in choosing the best strategy. These targets are achieved using dynamic simulations (IESVE software) which provide yearly energy assessments and calculations of Key Performance Indicators (KPIs). These components are merged in a Collaborative Design Platform, which provides the access to all the embedded tools and the visualization of the results through an intuitive Graphical User Interface. Figure 1 reports a scheme of the platform.
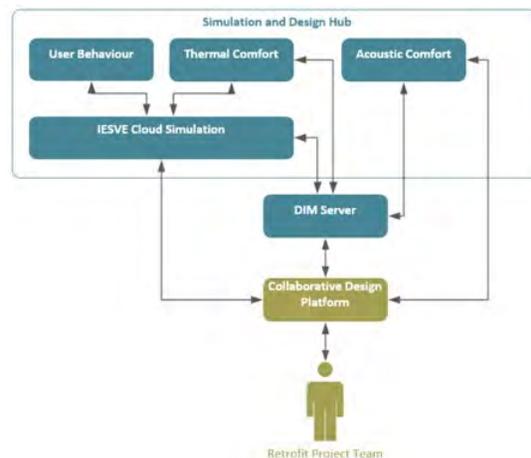

Figure 1. Scheme of the NewTREND platform.

A key improvement of this methodology concerns the inclusion of the occupants' perspective in the decision-making process. In fact, the evaluation of different retrofit scenarios is investigated considering both users' comfort (thermal and acoustic) preferences and the human-building interaction. According to this people-centred perspective, three modules have been developed. The thermal comfort and acoustic comfort modules perform a post-processing analysis on the simulation data to provide simple comfort indicators for the different design alternatives. The behavioural module includes the human component inside the simulation process since it is directly coupled with the IESVE engine.

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[2] https://www.multicomfort.co.uk/media/1096/saint-gobain-uk-home-health-and-wellbeing-report-summary.pdf

Thermal Comfort Module

Thermal comfort is a subjective quantity which has to be measured and assessed using a statistical approach. The tool offers an evaluation of the thermal comfort conditions for each room of the studied building. The algorithms post-process the data provided by the IESVE simulation or measurements, according to the user selection both in terms of comfort model (i.e. predictive and adaptive) and season (i.e. heating, cooling). The tool displays KPIs related to the thermal comfort assessment for each investigated retrofit scenario, calculated as the percentage of occupied hours out of the optimal ranges provided by predictive and adaptive comfort models according to EN 15251 (2007). It receives the input data from the IESVE cloud energy simulation and, after the post-processing analysis, stores the results in the DIM server. In addition, this module provides a sensitivity analysis, based on Monte Carlo method, to determine which parameter has the highest impact of thermal comfort. In this way the designer has the possibility to address specific issues to be solved with the retrofit. The tool has been tested simulating a room of a monitored building to guarantee the reliability of the obtained results (Naspi et al. 2018a). After simulating the actual thermal condition, two retrofit configurations have been selected and applied. The KPIs related to the three different scenarios are illustrated and compared to investigate which solution is to be preferred.

Acoustic Comfort Module

The acoustic comfort module is composed of algorithms for the assessment of indoor acoustic comfort at building level, according to equations of EN 12354-3 (2017). The improvement of the acoustic comfort is obtained by applying building envelope interventions on the basis of the evaluation of district noise levels (through measurements - EN 16283-3 (2016) - or predictive calculation models[3]). After simulating the current building condition, the tool performs post-retrofit simulations according to the retrofit interventions selected by the user. The output of each simulation process is a specific KPI, calculated by assignment of a score according to the measured/calculated indoor sound pressure level, which allows the assessment of the indoor acoustic comfort and the comparison between the pre and post retrofit configurations. The KPI provides to the designers a clear identification of the best retrofit option on the building envelope to improve the indoor acoustic comfort. The tool, integrated in the SDH, communicates with the DIM server to receive the required input data. The investigation of the potentialities of the tool occurred following several steps. At first, an extensive data collection by acoustic measurements has been performed in a residential building, settled in Ancona (Italy), to evaluate the actual comfort condition calculating the acoustic KPI. Then, applying different retrofit scenarios, the tool simulates the post-retrofit conditions and offers a comparison of pre and post scenarios through the KPIs.

The Behavioural Module

The module consists of two behavioural functions that predict occupants' interaction with windows and electric lights in offices. The algorithms have been developed using experimental data acquired for a full year in a University building in Italy. People presence, environmental parameters and the status of the devices have been continuously recorded (10 min sampling time) in three offices equipped with sensor networks (Naspi et al. 2018a). Following the approach proposed by (Wang et al. 2016), the influence of environmental variables and time-related events on users' behaviours has been investigated. Window adjustments are driven by both indoor and outdoor temperature; while the lights are switched on and off in relation to the decreasing of the work-plane illuminance and to the users' departure, respectively. Identified the triggers, the coefficients of the equations have been

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[3] Directive 2002/49/EC. Directive of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise. Official J Eur Communities 2002; L189: 12-25.

tuned using regression methods. The co-simulation approach between the module and the IESVE engine allows the data exchanges during the simulation run-time. This approach offers a considerable modelling improvement since the operational schedules are dynamically defined at each time step, according to the module outputs. The integration and the predicting capabilities of the module have been tested simulating a portion of the case study. Ventilation and lighting profiles are stochastically defined; while heating and occupancy ones are set according to ASHRAE standards (2004). The results obtained using the behavioural module have been compared to those related to a standard simulation (i.e. deterministic results). Then, both of them have been evaluated in relation to the monitored data to assess which approach would have made the best predictions.

RESULTS

To demonstrate the functionalities of the tools, they have been applied to assess different retrofit scenarios to a building of the UNIVPM campus, located in Ancona (centre of Italy), and built in the seventies.

Thermal Comfort

Thermal comfort module was applied to heating season. Figure 2 shows that, before retrofit, the building is uncomfortable since the average operation is at the limit of the lowest comfort zone. This is also confirmed by the KPI, which is for more than the 60% of the time in "cold" conditions, calculated considering the category II as reference (±0.5 PMV as boundaries). The first retrofit configuration (Retrofit 1), concerning the application of envelope thermal insulation, moves the building to category II. This intervention produces only a partial improvement of the comfort conditions since the KPI is not sufficiently high. The second retrofit scenario (Retrofit 2) concerns the windows replacement and the improvement of the heating system. The design condition and its deviation reach the higher building category (±0.2 PMV). Also, the KPI shows a number of cold hours lower than the 2% of the total building operation.
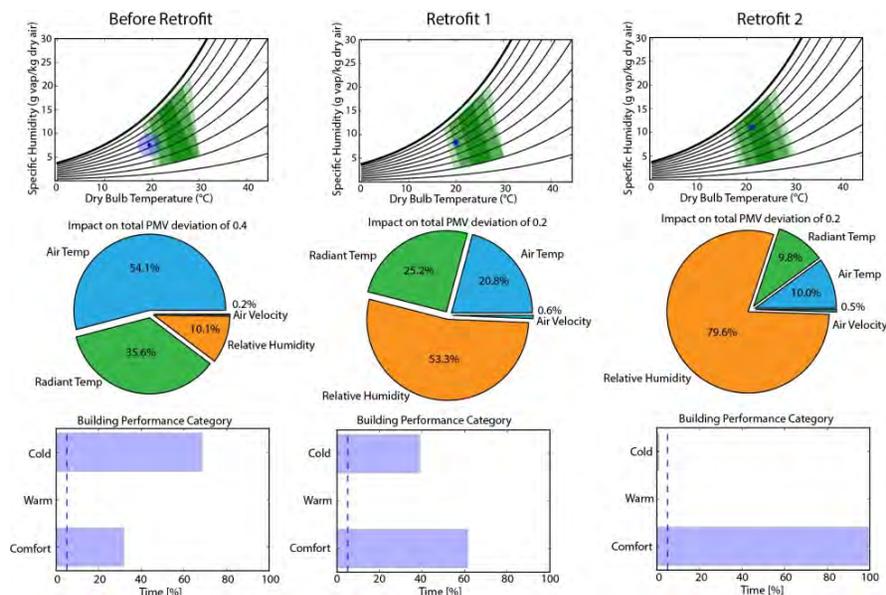

Figure 2. Results from thermal comfort analysis for heating season with predictive model.

Acoustic Comfort

The main outcomes of the acoustic comfort tool are the comparisons both between actual and retrofitted conditions and between different retrofit designs, using KPIs. Figure 3 shows the

influence of four types of interventions, with increasing impact. The first two scenarios concern only one action: the addition of an external insulation layer (case 1) and the substitution of the windows (case 2). The last two retrofit options are connected to concurrent operations: addition of an external insulation layer, substitution of windows and small elements. The key difference between case 3 and case 4 regards the features of the windows, which are much more performing in the second instance.
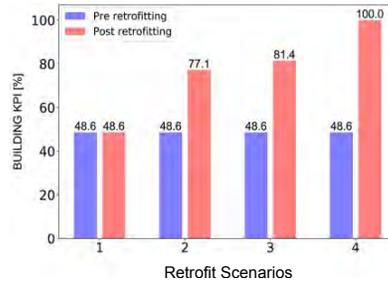

Figure 3 KPIs comparison of pre and post scenarios.

The analysis highlights that the external insulation has no impact on improving the acoustic condition while changing the type of windows provides an increase of 28.5% in the KPI value. The preferred comfort assessment is reached in case 4. In fact, combining several interventions and enhancing the features of the components, the KPI raises of 51.4%. Such assessment, clearly identifying the most effective acoustic retrofit solution, aids the users in selecting the design strategy and in avoiding time and money wastes.

Behavioural Module
The lighting and ventilation profiles obtained applying the behavioural module are compared both to standard profiles and to real users' behaviours. To perform the comparison, a sample of 14 days during the non-heating season has been selected (to avoid the influence of fixed heating profiles on the results). Figure 4 presents the lighting and ventilation profiles during two representative days. The real users' behaviours (blue dashed line) have been examined in relation to the behavioural (red solid line) and standard (grey dotted line) profiles.
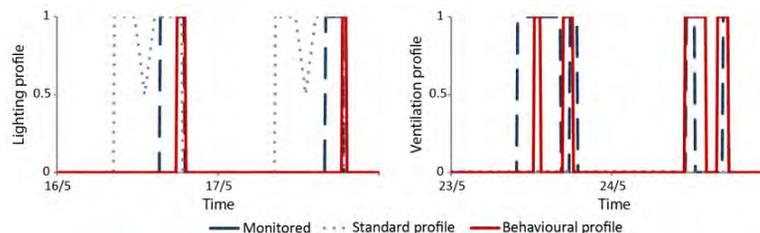

Figure 4. A two-day comparison of lighting and ventilation profiles.

Table 1 summarises the analysis for all the 14 days, reporting the percentage of time with lights on and windows open and the percentage difference (i.e. error) between simulated and real actions. The outcomes highlight that both the simulation approaches tend to overestimate the lighting use and to underestimate the window openings. However, the behavioural module minimises the discrepancy with actual data, especially for the lighting use (Δ=+5.1%), with a consequent deviation of 10% on the prediction of energy consumption, compared to standard profiles (Naspi et al. 2018b).

Table 1. Errors of Standard and Behavioural profiles in relation to the real data.

Lighting Profile	% of time lights ON	Δ% with real	Ventilation Profile	% of time windows OPEN	Δ% with real
Real	8.5	--	Real	24.9	--
Standard	42.4	+33.9	Standard	1.9	-23
Behavioural	13.6	+5.1	Behavioural	8.2	-16.7

DISCUSSIONS

The tools presented in this work are useful to support the retrofit design with deep investigations of comfort issues. Acoustic and thermal comfort modules can be a support for the selection of the optimal retrofit solution, addressing buildings pathologies. Also, the behavioural module provides a substantial empower to the simulation results since it reproduces the human-building interaction more accurately than standard profiles.

CONCLUSIONS

The paper presents the framework of the NewTREND cloud platform and, in particular, three embedded tools. The thermal comfort and acoustic comfort tools provide clear and effective evaluations between different retrofit scenarios using KPIs. The behavioural module reproduces the human-building interaction during the simulation, overwriting standard schedules. These tools, including the human component under different perspectives, support the decision-making process and aid the design team in selecting the optimal retrofit option in terms of energy efficiency and occupant's comfort expectations.

ACKNOWLEDGMENT

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