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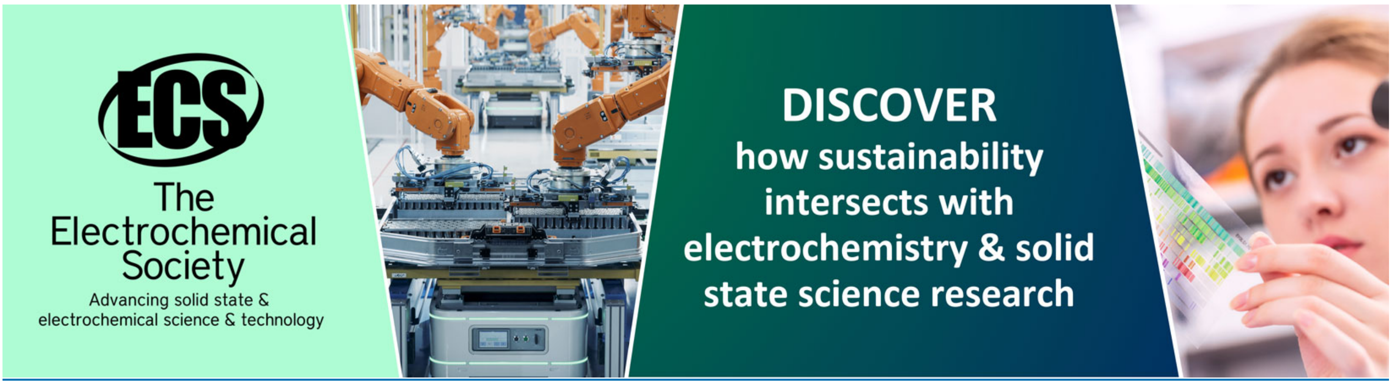

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Comparing different approaches to define shading control threshold via a new automatic building simulation platform

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Abstract. Active shading systems are essential to prevent heat gains in buildings and reduce the risk of overheating phenomena. The control logic must avoid overheating while allowing solar gains during heating hours. In general, smart control is based on a temperature and/or solar irradiation threshold; however, innovative informatics tools now allow optimising these thresholds based on specific building and climate characteristics. The paper presents a new building energy dynamic simulation platform used here to define optimal shading control thresholds for free-running and mechanically cooled spaces. Several shading control approaches are applied and compared, considering fixed hourly schedules, controls based on standard thresholds, and optimised thresholds with the tool. The analysis is performed considering the sole summer. The approach shows how the developed platform and the proposed methodology can optimise shading control thresholds, considering the specific building characteristics and the local climate conditions, consequently reducing energy needs or thermal discomfort conditions.

1. Introduction

Active shading and ventilation can have significant impacts on comfort and energy consumption, impacting heating, cooling and for shading also lighting energy needs. Nevertheless, their effectiveness is largely depending on the associated control strategies, although in the majority of cases, they are still manually controlled with a lack of effectiveness [1,2]. Different logics are employed for controlling movable shading activation and ventilative cooling, including different levels of complexity. Focussing on shading systems, [3] analyses the impact of a solar radiation setpoint for controlling external venetian blinds, while studies on roller shadings can be found in [4]. Regarding activation logics, experiments on shading during occupancy are conducted in [5], while [6] studies the application of fuzzy logic shading and lighting controls, including mobile user applications, while some predictive controls are analysed in [7]. In [8], the shading activation focuses on the impact of visual comfort in terms of glare reduction and amount of daylighting, while energy consumption studies on a climatised building are found in [9]. Nevertheless, from an applicability point of view, the optimised thresholds or the activation signal, whenever defined, can be processed by local building management systems or by self-actuation, informing building occupants via alerts [10]. It may be underlined the need to develop fast approaches to define optimised thresholds for specific buildings and climates to define simple actuation control logics.

This paper presents some initial results of a large work, part of the H2020-funded project PRELUDE (958345), supporting the exploitation of shading and ventilative cooling local potential in increasing summer comfort in both free-running and climatised spaces while also reducing cooling loads in the latter. Different control optimisation logics are studied and developed, ranging from low to high levels of smartness: i. random user control (no smartness); ii. use threshold control logic (low to medium smartness); iii. forecasted optimised schedules for the next 24h via white box modelling optimiser and surrogate modelling optimiser in a digital twin perspective (high smartness). This paper focuses on the ii. level of smartness, considering the sole shading control. It focuses on calculating optimal threshold values for shading activation and comparing several control values.

2. Methodology

In the following paragraph, the strategies of category ii. (low to medium smartness) are described. Such strategies are generally based on the adoption of control thresholds to support system activation. Focusing on shading systems, this paper considers as control variables air temperature and solar radiation (global horizontal). Different smartness levels are considered inside the ii. category, ranging from standard thresholds, generically assumed from literature or empiric knowledge, to optimised thresholds defined with a sensitivity analysis by dynamically simulating the specific building case under local typical climate and usage conditions. The paper supports the usage of a newly developed tool for the latter case and compares results between the different approaches. Analyses and optimisations are based on dynamic energy simulations, run using EnergyPlus and managed via the PREDYCE Python library [11], developed by the authors, to support input changes and sensitivity analyses with respect to a reference case without shading. The description of the method is pursued by detailing a sample application case, assuming a typical flat model located in Turin featuring one zone and one window only. The building is simulated in free-running (without systems) and mechanically cooled and dehumidified mode (climatised building). Simple HVAC is assumed with a set point of 26°C, including a 60% relative humidity dehumidification control. Final electrical energy is calculated using a SEER of 6.5, in line with typical market references for new installations.

2.1. Design of the experiment, including the selected model

The analysis includes a baseline case (A), different reference cases (B), and optimised cases (C). The baseline case A consists of the sample building without a shading system; the reference cases (B) adopt standard shading activation logics; the optimised cases (C) include several optimisation analyses for shading threshold activations. Reference cases (B) are adopted to test and describe the behaviour of typical control logics based on thresholds, e.g. by setting a fixed shading profile driven by occupancy or empirical temperature/solar global horizontal radiation (GHI) values. Differently, optimised cases (C) use PREDYCE to select the best control threshold values to reduce the cooling energy needs for the mechanically cooled and dehumidification case and the number of discomfort hours for the free-running case assuming the adaptive thermal comfort model (EN 16798-1). The variation parameters include, as individual or combined thresholds, the ambient temperature (Tamb) and the GHI, both able to be measured with standard sensors. The considered combinations of parameters are reported here. **A1**: baseline; **B1**: shading during occupancy; **B2**: shading from 10 a.m. to 5 p.m.; **B3a**: shading when Tamb is above 24 °C; **B3b**: shading when GHI is above 120 W/m^2; **B4**: same thresholds of B3a and B3b combined; **B5-ems**: shading when the difference between Tamb and the running mean temperature of the day, calculated in line with EN 16798-1 for the adaptive thermal comfort model, is above 2°C; **C1** optimises Tamb – range [19–25 °C] – and GHI [80–200 W/m^2] at the same time; **C2a** optimises Tamb; **C2b** optimises GHI; **C3-ems** optimises the activation difference [0–5 °C] between the Tamb and the running mean temperature of the specific day. Both B5 and C3-ems cases require the adoption of a proper EMS coding structure in EnergyPlus. All these cases have been applied to a sample demo apartment, representative of typical flats in European building stock – see also [12] – considering a two-flat-per-floor distribution. The apartment – see Figure 1 – is divided into six thermal zones and features windows on each side of the building, confining with the outside. Confining flats are assumed to have the same temperatures. The windows are double glazing, clear, Low-E, argon-filled glazing, while the wall has a U-value of 1.589 W/(m^{2}K). The shading system used for the sample simulations consists of external movable blinds with slats of 25 mm width and 1 mm thickness, with front and back solar reflectance coefficients of 0.8 and slat separation of around 18 mm. The chosen weather file consists of real weather data gathered in 2022 in Turin, Italy, using a PRELUDE-POLITO meteorological station (Thiess Climate US and RAZON+ sensors) cloud-connected to PREDYCE for real-weather simulations. EN 16798-1 comfort categories are assumed: the free-running performance is measured with the adaptive comfort model considering cat. II boundaries; the climatized-case performance is measured by evaluating the predicted mean vote (PMV), considering discomfort outside ±0.7, and the correlated predicted percentage of dissatisfied (PPD). Results can be subject to modification if different shadings are adopted.

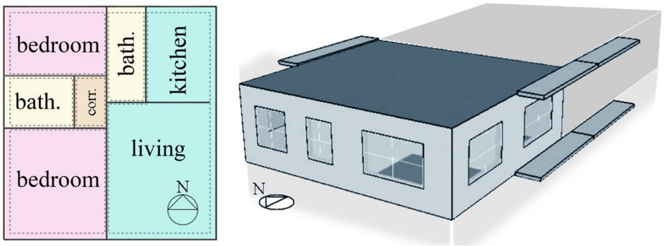


Figure 1. The adopted representative building flat model

3. Results

Results analyse thermal comfort conditions, considering the right model in line with free-running or mechanical mode, and for the latter also energy needs. Tables 1 and 2 summarise the main results.

Table 1. Results for shading activations in free-running mode. The highlighted rows represent the baseline, the best reference case and the best-optimised case.

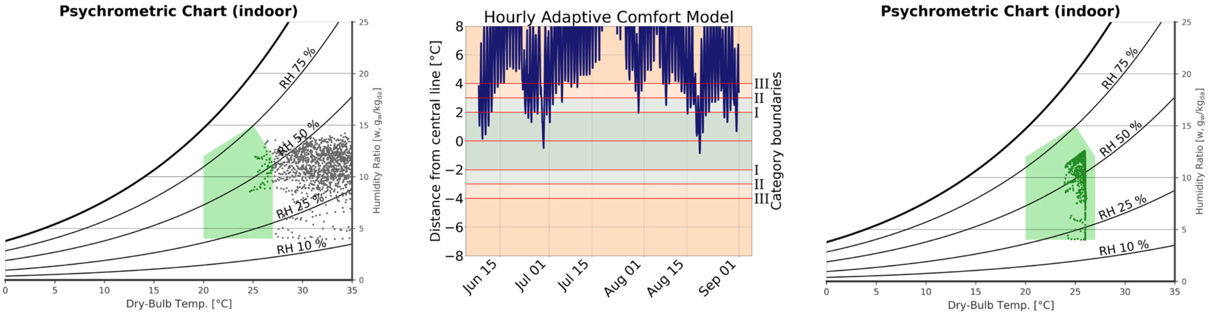
Free-running	mean ACM dist. (>0)	cumul. ACM dist. (>0)	mean ACM dist. (abs)	cumul. ACM dist. (abs)	hrs discomfort	hrs cat I	hrs cat II	hrs cat III	hrs cat IV
A1	**7.13**	**14558.12**	**7.13**	**14558.22**	**1775**	**113**	**153**	**170**	**1605**
B2	5.43	11086.53	5.44	11093.78	1535	302	204	233	1302
B3a	4.95	10094.78	4.95	10105.86	1448	357	236	230	1218
B3b	**4.92**	**10043.52**	**4.93**	**10055.69**	**1442**	**364**	**235**	**228**	**1214**
B4	4.97	10137.87	4.97	10147.85	1453	353	235	232	1221
B5-ems	5.36	10931.45	5.36	10936.28	1522	297	222	240	1282
C1	4.85	9903.16	4.86	9917.27	1418	378	245	220	1198
C2a	4.93	10059.34	4.93	10071.42	1443	360	238	228	1215
C2b	**4.85**	**9896.66**	**4.86**	**9910.47**	**1418**	**378**	**245**	**221**	**1197**
C3-ems	5.14	10487.97	5.14	10495.08	1484	325	232	236	1248

Table 2. Results for shading activations in climatised mode

Climatised & Humidistat	Q_c	Q_h	POR	h discomfort	$Q_{el.final}$
A1	**52.48**	**0**	**0.68**	**1503**	**8.07**
B2	43.04	0	0.56	1234	6.62
B3a	**40.79**	**0**	**0.48**	**1070**	**6.28**
B3b	40.67	0	0.49	1082	6.26
B4	40.97	0	0.5	1099	6.3
C1	40.44	0	0.48	1060	6.22
C2a	**40.56**	**0**	**0.48**	**1050**	**6.24**
C2b	40.44	0	0.48	1061	6.22

3.1. Baseline case (A)

The baseline case A starting conditions are analysed in Figure 2, plotting indoor conditions on a psychrometric chart for the free-running mode (a) and the climatised mode (c). In the free-running mode, conditions are too hot and humid with respect to both the Givoni comfort zone (a) and the adaptive thermal comfort conditions (b), underlining the need for countermeasures.



(a) (b) (c)

Figure 2. Baseline case A results. Free-running mode: (a) psychrometric chart and (b) adaptive thermal comfort hourly distribution; climatised mode: (c) psychrometric chart.

3.2. Reference cases

When shading is activated in free-running mode (see Table 1), the number of discomfort hours is reduced by 20% with respect to case A, while hourly points in the adaptive thermal comfort model are brought down to higher comfort categories. Even for very simple shading activation scenarios, hence based on a fixed schedule, an increase of 50% hours in comfort is underlined. The best-case-B scenario is B3b, where shading is activated with a solar radiation threshold only. When shading is activated in climatised mode (see Table 2), for every strategy, cooling consumption is reduced by around 20%, as well as the discomfort, proving the effectiveness of the method. The best strategy for mechanical mode is B3a, with shading activation depending on external temperature only. For both modes, B4 behaves worse since the shading is active when solar radiation and temperature are above a certain threshold at the same time, hence shading is activated less frequently than B3a or B3b.

Table 3. Optimised parameter values for minimum discomfort

	Free-running			Climatised mode	
Case	Tout [°C]	GHI [W/m2]	ΔT [°C]	Tout [°C]	GHI [W/m^2]
C1	21	60		19	80
C2a	23			19	
C2b		60			80
C3-ems			0		

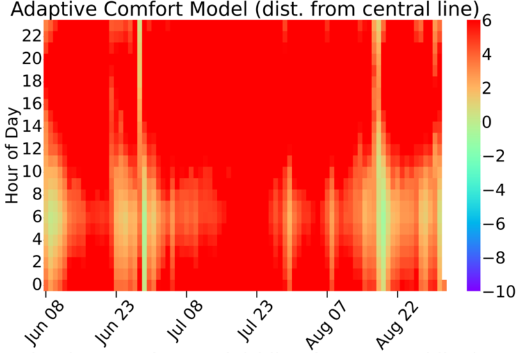
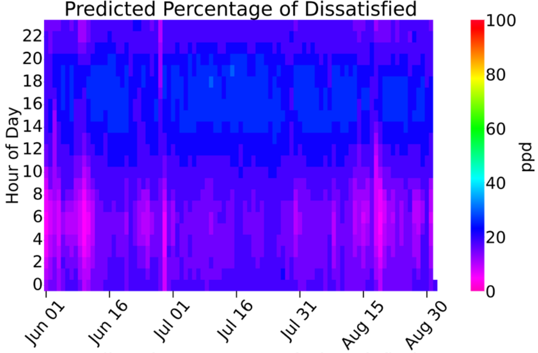
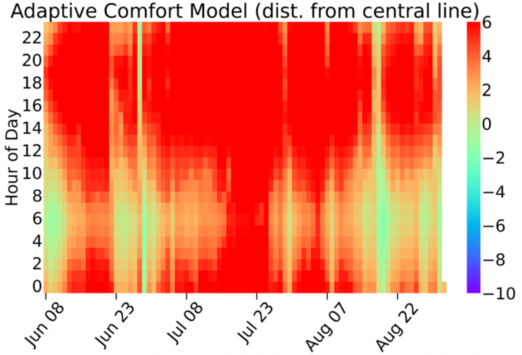
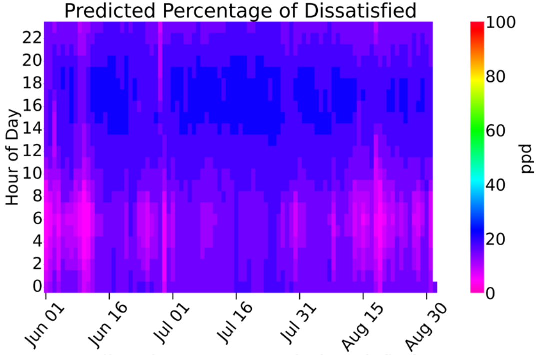
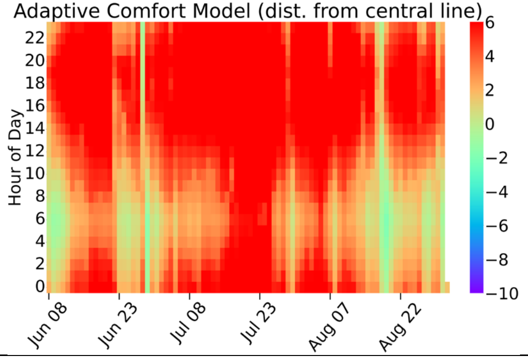
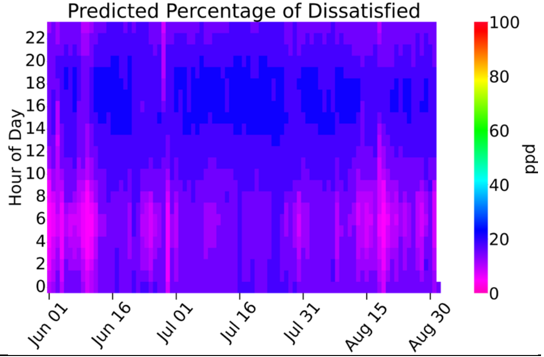
3.3. Optimised cases

This section discusses the results of the optimised cases via PREDYCE. For the free-running mode, the best case (C2b) is achieved when the GHI threshold is optimised (Table 1). Results are slightly better (range 2–5%) when compared to the reference case B3b, demonstrating the importance of correct tuning of the threshold parameter. The optimised parameters are shown in Table 3 (left). With climatisation, the best-optimised strategy considering both consumption and comfort is the C2a (Table 2), based on an outdoor temperature threshold. Optimised parameters are shown in Table 3 (right).

3.4. Comparison between results (thermal comfort)

Table 4 reports thermal comfort results for simulations performed in both free-running and climatised modes to compare the baseline case A, the best-identified reference case B, and the best obtained optimised via PREDYCE case C. Considering the free-running, carpet plots show the time-distribution of distances from the adaptive thermal comfort central line. The comparison shows how shading may considerably reduce the discomfort hours and attenuate discomfort temperature peaks. Additionally, the optimised threshold case is slightly better (range 2−5%) than the best reference one, while the reference selected one is based on the specific building simulation results, including already an evaluation step. Similar results are also obtained for the mechanically cooled and dehumidified mode, focussing on the PPD index. In this mode, it is possible to see that shadings can reduce, especially during the afternoon, the percentage of predicted dissatisfied, increasing the expected comfort quality.

Table 4. Thermal comfort comparison between baseline (A), reference (B) and optimised (C) cases. (left) results for free-running mode (adaptive thermal comfort); (right) PPD index (climatised mode).

Case	ACM (free-running)	PPD (climatised)
A1 (baseline)		
Best reference		
Best optimised via PREDYCE		

4. Discussion of results and conclusion

For the presented tests, shading is always demonstrated to have a benefit in decreasing the perceived discomfort of tenants since it can reduce internal building temperature by preventing excessive solar gains. For the free-running mode, the solar radiation control threshold is considered the most influencing factor when choosing the strategy for shading activation. For the climatised mode, a threshold based on outdoor air temperature is better by 15% to reduce discomfort and consumption with respect to the standard hourly schedule. For every kind of strategy, a correct tuning of parameters is demonstrated to always lead to benefits in terms of comfort and energy needs. However, it may be underlined that, at least under the testing climate, shading may benefit by being used with natural heat dissipative techniques, such as ventilative cooling. Thanks to the PREDYCE tool, a statistical correlation analysis was finally conducted to discuss results by connecting input threshold variations with impacts on the mentioned target variable. Results are shown in Figure 3, including the impact of ventilation on the free-running building. The analysis confirms the positive but limited impact of shading and the above hypothesis that in that climate, ventilative cooling may strongly support thermal comfort by dissipating residual overheating under positive environmental conditions.

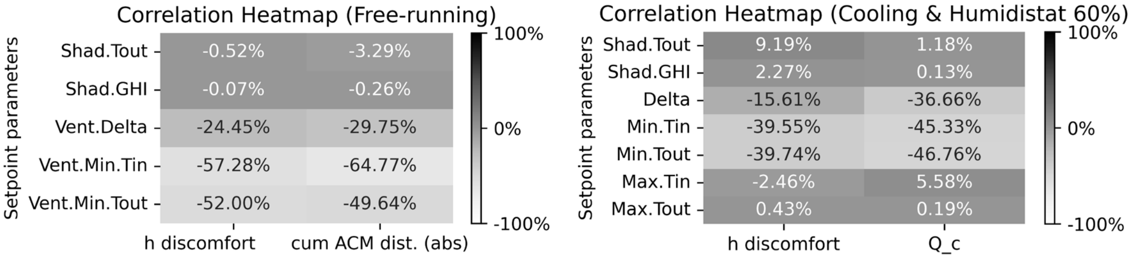


Figure 3. Correlation heatmaps for free-running (left)and climatised mode (right).

The proposed approach in defining and checking different threshold initial choices is demonstrated to be useful in supporting the design of shading control logic, allowing the identification of the correct local parameter definition. Additionally, the optimisation approach via PREDYCE helps in tuning thresholds on the base of local climate and building characteristics. The possibility of analysing the correlation impacts of different control variables is also helping in orienting design choices to the most effective ones. In the end, it has to be pointed out that the analysis proposed in this paper is limited to one specific type of shading with specific characteristics of coverage and solar reflectance; the study can be expanded by applying the proposed methodology to other types of shadings possibly made of different materials, by which the difference in discomfort hours given by the proposed strategies may potentially be higher or lower.

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