

# ADAPTING FAÇADE PERFORMANCES TO CLIMATE CHANGE IN NORTHERN EUROPE: ANALYSIS OF FUTURE SCENARIOS FOR AN OFFICE BUILDING IN STOCKHOLM

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**ABSTRACT.** Future climate change will affect many human activities and sectors. Among those, the built environment will face several challenges about the varying climate conditions, including increased demand for summer cooling and related heat stress indoor conditions. In this framework, the paper presents the results of a recent study that investigated the global warming impacts on energy demand and indoor climate comfort for an office building in Stockholm over the next 50–60 years. The future climate conditions were investigated in 2070 and 2080 with different climate morphing approaches. Three different passive cooling solutions to decrease the cooling demand (such as external roller shade, electrochromic glazing, and internally ventilated shading) have been preliminarily assessed about thermal and optical properties, then integrated into the building energy simulation software IDA-ICE to evaluate the building energy performances regarding different Swedish climates, and finally economically estimated with a simplified LCC analysis. The results indicated that an increment of the cooling demand from 3 up to 24 kWh/m<sup>2</sup> and a reduction of the heating usage of 20–50 % will be experienced in 50–60 years. The different weather data morphing approaches displayed the inherent uncertainties when future evaluations are performed, although similar weather patterns were found. The improvement of the solar and optical properties indicated a lower cooling and ventilation usage with reductions of about 10–16 %. The electrochromic technology reported the lowest cooling demand (decrease up to 24 %), while the internally ventilated shading option outperformed the others with an annual energy consumption 4–9 % lower and the lowest LCC.

**KEYWORDS:** Climate change, building design, passive cooling solutions, solar control techniques.

## 1. INTRODUCTION

World population is constantly increasing, and with it also its needs, consumptions, and emissions. In the European Union (EU), research and analyses about energy consumption and greenhouse gases (GHGs) emissions reported how the built environment was responsible in 2018 for approximately 40 % of the energy consumption and 36 % of all the CO<sub>2</sub> emissions in the EU countries [1]. In Sweden, the building and services sector represents the predominant one, accounting for more than 34 % of the overall energy usage [2]. Buildings are usually designed and constructed to provide a service life of 50 years, consequently raising the importance of a detailed preliminary study in the building design process to assess its behaviour and response to possible different climatic conditions. The expected air temperature increase will soon promote space cooling as one of the major challenges in the building sector [3], thus design solutions that can decrease the cooling demand of the buildings will come

to be of crucial value. Among those, passive cooling strategies, which take advantage of natural and renewable resources to reduce the building energy usage, can be a vital contribution.

Nowadays the fast progress of a worldwide climate change is evident with several environmental alterations. The Intergovernmental Panel on Climate Change (IPCC) reported the risks of profound changes in the Earth system given by the increase in GHGs emissions [4]. The global rise of average temperature is the foremost and most detectable aspect, with a measured warming of 0.85 °C over the period 1880–2012 [5]. This increase is mainly connected to the increase in CO<sub>2</sub> emissions and the related greenhouse effect, directly connected to both human activities and natural causes [6].

The construction sector in Sweden is regulated by the Swedish Board of Housing, Building and Planning (Boverket), which determines the constraints in terms of energy demand and indications for the indoor com-

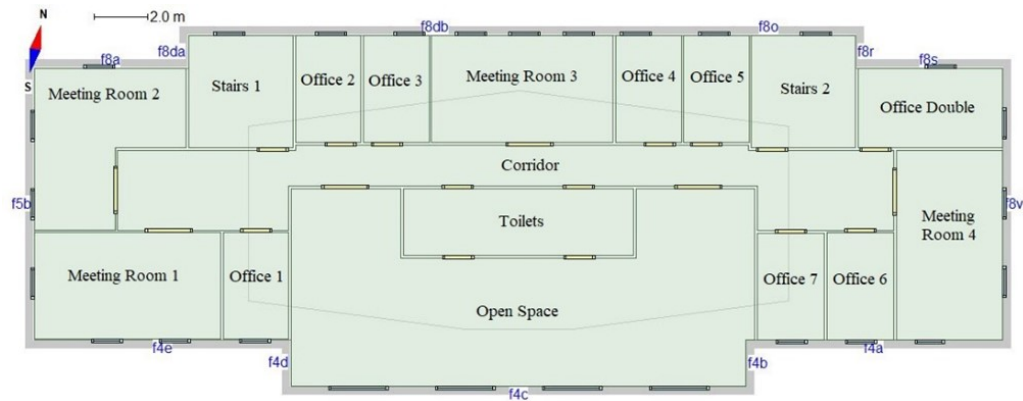


FIGURE 1. Typical floor layout.

fort together with other national and international authorities. In this research, the building code Boverkets Byggregler (Boverket's building rules – BBR) with modification up to BFS 2019:2 (“BBR 28”) was taken into consideration for the energy performances evaluation of the case study [7]. Considering an office building, the energy performance (expressed as primary energy) is limited to  $80 \text{ kWh/m}^2 A_{\text{temp}}$ , and the envelope performance (considered as  $U_{\text{m-value}}$ , average heat transfer coefficient) is limited to  $0.60 \text{ W/m}^2\text{K}$ . For what concerns the indoor comfort, specific recommendations for thermal comfort in office buildings and workplaces are reported by the Swedish Work Environment Authority (SWEA) based on the provisions given by the EN 7730 [8]. The indoor operative temperature ranges are  $20\text{--}24 \text{ }^\circ\text{C}$  in winter and  $20\text{--}26 \text{ }^\circ\text{C}$  in summer, for an office building. Finally, indoor visual comfort is restricted directly by Boverket which takes into considerations a minimum level of Daylight Factor (DF) of 1% for rooms with direct access to sunlight in office buildings [7].

In cooling-dominated buildings external shading devices are efficient tools to block the direct and part of the diffuse solar radiation. According to Kunwar et al. [9], the introduction of external roller shades enables an increase in energy savings, with a cooling demand decrease up to 26%. While an in-situ study carried out by Ip et al. [10] showed an annual energy demand reduction of 16% and a maximum reduction of the air temperature of  $3.5 \text{ }^\circ\text{C}$  when external roller shades have been implemented instead of internal venetian blinds into an office building in Brighton (U.K.).

Cannavale et al. [11] recently analysed different kinds of electrochromic (EC) glazing for a medium-sized office building, obtaining a reduction of the annual energy demand up to 23% and a cooling usage reduction of 60%. Ajaji & André [12] reported enhancements of the indoor thermal and visual comfort performances for an office space, limiting the indoor temperature and the risk for over-illumination.

In the case of internal shading systems, which are known to be less performing, a promising solution cou-

ples the system with an exhaust air extraction system to remove the stored heat before it is re-irradiated into the room. Denz et al. [13] considered in their study a similar integration in the gap between window and SD. In this research, the g-value of the system has been reduced by 50% with a cooling energy demand decrease of 25%. Similarly, Gustafsson & Säfblad [14] evaluated an internally ventilated system, varying several parameters, such as gap width, shading's fabric, and air flow rate, obtaining a g-value reduction up to 45%.

## 2. METHODOLOGY

### 2.1. STOCKHOLM CASE STUDY

The selected case study is a typical modern 10-storey office building, with the two main façades facing north and south. The building is located in the central urban area of Stockholm city (Sweden) and fulfils the latest building regulations and construction standards. The total floor area is  $430 \text{ m}^2$ , with 57 occupants per floor, divided between single offices ( $10 \text{ m}^2$ ), meeting rooms ( $26\text{--}28 \text{ m}^2$ ) and an open space of  $115 \text{ m}^2$ . The floor height is 2.6 m and the windows have dimensions  $1.1 \times 2.2 \text{ m}$  and  $2.2 \times 2.2 \text{ m}$ , for a total WWR of 23.3%. A schematic representation of the typical floor is reported below in Figure 1.

The parameters of the case study model are set into the IDA-ICE software to represent a typical office usage, in accordance with the prescriptions of the Swedish building code (BBR 28). Among those, general construction parameters, internal gains settings, and the AHU system are defined also according to the Swedish Building Environmental Certification System “Miljöbyggnad” [15] and the Sveby (Standardize and Verify Energy Performance in Buildings) “User data for Office” [16], when not specified by the building code.

Afterwards, in order to analyse the IDA-ICE results, the energy consumption is divided into electric, district, and tenancy demand, as required by Swedish building regulations. The purchased energy is multiplied by the Primary energy factor per energy carrier (PE), except the consumption due to the tenancy use,

	Glazing Units					Screen properties			
	G1	G2			G3	S1		S2	
		Clear	Int. 1*	Int. 2**		Tinted			
$T_{vis}$	70 %	63 %	21 %	6 %	2 %	60 %	$T_{vis}$	22 %	4 %
$Rf_{ext}$	11 %	11 %	6 %	5 %	5 %	14 %	$T_{sol}$	24 %	4 %
$Rb_{int}$	13 %	12 %	10 %	9 %	10 %	17 %	$R_{sol}$	39 %	74 %
g-value	0.31	0.47	0.16	0.09	0.06	0.27	O.F.	14 %	2 %
U-value [W/m <sup>2</sup> K]	1.0	1.4	1.4	1.4	1.4	1.0	$EmiS_{front}$	76 %	19 %
							$EmiS_{back}$	76 %	81 %

\* Int. 1 = Intermediate state 1.

\*\* Int. 2 = Intermediate state 2.

TABLE 1. Solar control glasses performances and Screen fabric properties.

and the energy demand for the electric cooling is further increased by the electric cooling factor (1.875) in accordance with section 9:2 of BBR 28, which must be considered in buildings with an installed electric input for space heating and hot tap water below 10 W/m<sup>2</sup>.

## 2.2. SOLAR CONTROL TECHNIQUES EVALUATION

In this paper, the performances of triple glazed units with different solar and light properties and under different shading conditions were assessed. The shading strategies consist in an external vertical awning with a roller blind (G1), electrochromic properties (G2), and an interior reflective fabric screen fabric with a ventilated air gap (G3). The external and internally ventilated shading techniques are characterized by a high selectivity solar control glass pane and a low-E pane, respectively on the outer and inner glass panes. The shading devices used are a roller screen made of a composite fabric in a vinyl-coated polyester mesh for the outdoor use (S1), and a semi-transparent metallised roller screen with a higher solar reflection and lower emissivity for the indoor case (S2). The electrochromic solution has a dynamic glass pane instead of the high selectivity one. The optical and thermal properties of the insulated glass units and the screen fabric characteristics are reported in the following Table 1.

The overall optical and thermal properties of the different solutions are determined following the calculation methods provided by the European standards in matter of glazing and energy calculation for buildings ([17–19]). The calculations are carried out with the support of the software LBNL Window 7.7 [20]. Case G3 requires the assessment of the thermal and optical performances of the glazing-shading system when the exhaust air extraction is active. WIS tool [21] is used to assess the optimal ventilation rate and the relative thermal and optical performances of the system. A preliminary energy balance of a room is provided in accordance with the European standard EN ISO 52016-1:2017 [22].

The energy balance for the most critical hour of a winter, summer, and midseason day is analysed for

an office room with an airflow varying from 0.18 m<sup>3</sup>/h to 5.4 m<sup>3</sup>/h, in accordance with the results derived from the literature review ([13, 14]).

Then, the passive cooling solutions performances are subsequently introduced into the IDA-ICE model building performance simulation software, version beta 07, to assess the building energy consumption and the indoor thermal comfort for the office building under investigation [23].

## 2.3. CLIMATE SCENARIOS

The climate conditions investigated in this paper consist of the current climate of Sweden and two climate scenarios for the future conditions which consist of hourly data of temperature, relative humidity, wind speed and direction, and solar radiation. The current climate conditions (C1) are provided by the Swedish Meteorological and Hydrological Institute (SMHI) for city of Stockholm [24]. The future climate scenarios are based on the emission models provided by the IPCC, called “Representative Concentrations Pathways” (RCPs) [5]. The first future climate scenario (F1) was derived from a previous work by Tsaousoglou [25] for the year 2070 and RCP4.5, only considering the variation of the air temperature. The latter was initially increased by 5 °C in winter and 2 °C in summer with a linear variation in the transition months, and then manually modified with increased temperature up to 31.2 °C, to include variations in the amount of tropical nights and heatwaves periods [26]. The second future climate scenario (F2) was alternatively derived from the baseline climate data by EnergyPlus weather database for the location Stockholm-Arlanda [27]. The climate morphing was carried out with the support of the Climate Change World Weather Generator [28]. The climate scenario refers to the year 2080 and the forecasted scenario denoted as B1 [29], which projects the comparable amount of CO<sub>2</sub> emissions and reflects similar changes in the weather parameters by the year 2100 as for the RCP4.5 previously selected [4], due to limitations of the climate generator tool. In Figure 2 is shown the monthly average daily temperature in Stockholm for the three climate scenarios under analysis.

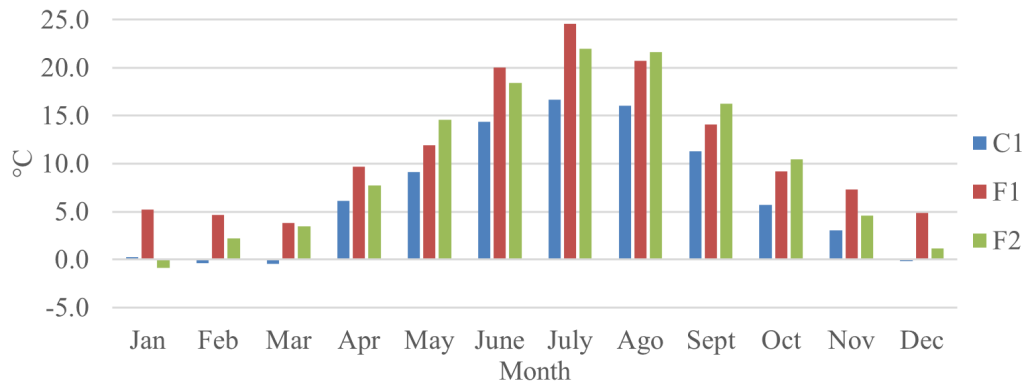


FIGURE 2. Monthly average daily temperature in Stockholm for the three climate scenarios.

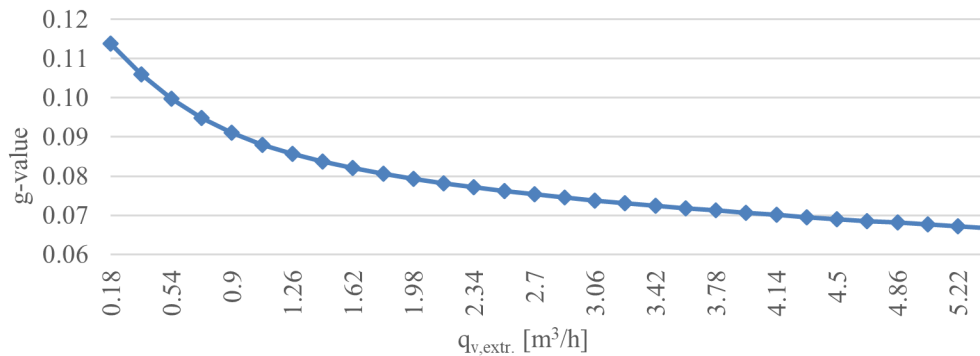


FIGURE 3. Graphical report of the g-value results with respect to the extraction airflow rate.

Element	U.M.	G1 + S1	G2	G3 + S2
Window	SEK/m <sup>2</sup>	3500	8500	3500
Shading	SEK/m <sup>2</sup>	3000	-	1100
Extraction	SEK/m <sup>2</sup>	-	-	977.1
Total	SEK/m <sup>2</sup>	6500	8500	5577.1

TABLE 2. Window and shading elements initial investment costs.

#### 2.4. LIFE-CYCLE COST ANALYSIS

The economic benefits of the three different solar control techniques are assessed with the support of a life-cycle cost analysis. In this research, the calculation is limited to only the window systems costs in relation to the total annual building energy costs. The initial costs for windows, shading elements, and the exhaust air extraction system are reported in Table 2. They were provided by WSP Sweden company [30], with reference to internal projects and by the cost list Sektionsfakta-VVS 19/20 by Wikells [31].

The initial investment and the later maintenance and renovation evaluations are related to the total window area of 750 m<sup>2</sup> (27 windows per floor, 10 stories). The maintenance and replacement expenses are evaluated based on a literature review about the different window systems elements. Average service life between 20–30 years were considered for the windows and ventilation system, while annual costs between 50–80 SEK/m<sup>2</sup> were defined for each solution. Sub-

sequently, to evaluate the life-cycle cost of the three options a pre-established working sheet provided by WSP Sweden is used. The calculation considers average prices for the energy carriers to evaluate the annual energy costs of the building over its service life (district heating 680 SEK/MWh, electric cooling and electricity 920 SEK/MWh), together with interest rate (3%), loan rate (2%), and price increase for the energy (3%).

### 3. RESULTS AND DISCUSSION

#### 3.1. SOLAR CONTROL TECHNIQUES

In case G3, the introduction of the exhaust air extraction showed a potential reduction of the g-value by 49% (corresponding to 0.067) for the maximum air flow studied, as presented in Figure 3.

Considering the analyses carried out on the office room model, the selected airflow for the exhaust air extraction was 3.24 m<sup>3</sup>/h, which corresponded to a g-value of 0.073 and an air velocity of 0.11 m/s. The latter configuration provided the best trade-off between air flow increment and heat loads reduction, showing the last considerable improvement in the energy balance of the room with heat loads and heat removal by the air conditioning reductions of respectively 43.8% and 21.7%. In Table 3 are reported the resulting values for the three techniques used in the further IDA-ICE simulations.

Finally, to manage the change of state for each of

	U.M.	G1 + S1		G2				G3 + S2		
		Clear	Drawn	Clear	Int. 1	Int. 2	Tint	Clear	Drawn	Extr.
$T_{vis}$	%	63	13.8	55.6	16.2	5.2	0.9	55	2.6	2.6
$T_{sol}$	%	27.3	6	30.4	7.1	2.3	0.4	23.2	1.1	1.1
g-value	-	0.312	0.083	0.367	0.127	0.078	0.055	0.267	0.131	0.073

TABLE 3. Optical and thermal properties of the three window systems.

Climate Scenario	Energy meter [kWh/m <sup>2</sup> A <sub>temp</sub> ]	G1	G2	% $\Delta_{G1-G2}$	G3	% $\Delta_{G1-G3}$
C1	Electric Cooling	3.2	2.9	-9.4%	3.0	-6.3%
	Electric Fans	7.2	6.9	-4.2%	7.2	0.0%
	District Heating	23.2	26.2	12.9%	23.6	1.7%
	Total	54.5	57.0	4.6%	54.9	0.7%
F1	Electric Cooling	24.4	20.6	-15.6%	21.9	-10.2%
	Electric Fans	8.2	8.1	-1.2%	8.5	3.7%
	District Heating	11.9	13.9	16.8%	11.6	-2.5%
	Total	67.7	65.4	-3.4%	64.9	-4.1%
F2	Electric Cooling	19.1	14.4	-24.6%	15.2	-20.4%
	Electric Fans	8.9	8.0	-10.1%	8.2	-7.9%
	District Heating	18.9	20.2	6.9%	17.6	-6.9%
	Total	69.1	63.9	-7.5%	62.7	-9.3%

TABLE 4. Annual building energy consumption in the different years for each solution.

these techniques on IDA-ICE, control macros based on levels of incident solar irradiation ( $W/m^2$ ) with an override connected to the outdoor air temperature have been implemented. Different solar irradiation levels have been considered for each façade and climate scenario depending on the characteristics of the window system.

### 3.2. CURRENT AND FUTURE CLIMATES

The annual energy demand and ventilation needs results are reported for the three solar control techniques and different climate scenarios in Table 4.

The results revealed an increment of the cooling consumption in both the future scenarios, efficiently reduced with the introduction of the electrochromic and internally ventilated solution. At the same time, the heating demand decreased, in accordance with the mitigation of the winter periods, showing a deficit of performance for option G2.

The results for the climates F1 and F2 take into consideration an optimization of the fans usage and a combine use of room units and AHU system for the summer period. The latter configuration was due to extreme cooling usage peaks and ventilation air flow initially detected for the scenario F1, caused by the coexistence of high outdoor air temperature and high relative humidity due to the manual alteration of the outdoor air temperature and unvaried relative

humidity. In the alternative scenario F2, built with the variation of all the weather parameters, these extreme conditions were not present, and the summer consumption was considerably decreased while the heating demand was increased, always remaining lower than the C1 results. The thermal comfort ranges, i.e. max values of PPD, min and max operative and indoor air temperatures, were respected in all the cases and seasonally analysed, reporting lower PPD values for the winter in the current climate, while more homogeneous results for the future climates.

### 3.3. LIFE-CYCLE COST ANALYSIS

In Figure 4 are reported the results of the life-cycle cost analysis, expressed in Swedish crowns, and divided by investment costs, building energy usage (district heating, electric cooling, electricity), general maintenance, and renovation. The EC technology resulted to be inappropriate for the case study. The costs due to the materials, installation, and renovation overturned the limited benefits in terms of annual energy costs. On the other hand, the internally ventilated solution showed the best results. The initial investment, operational and maintenance costs were improved, remarking the potential advantages of such technique also in a long-term perspective in relation to a changing climate.

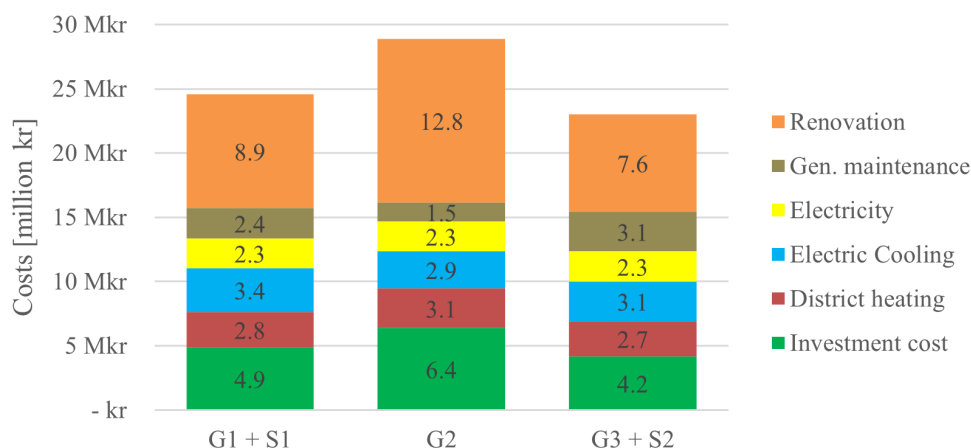


FIGURE 4. Graphical representation of all the present values and resulting LCC.

#### 4. CONCLUSIONS

Following a previous study on the climate change effects on the built environment for a building in Stockholm, this research evaluated the energy consumption and indoor thermal comfort variations for an office building equipped with different solar control techniques for the current and future climate.

- The internal shading with the extraction offered better performances than without it, for both the current and future climate, especially regarding the cooling demand of the building.
- The introduction of the EC technology and the ventilated shading did not considerably modify the energy behaviour of the building in the current scenario, while they successfully improved it in both future climates, decreasing the solar thermal load, lowering the maximum airflow required by the building, and thus reducing the size and related issues of the ventilation system.
- The initially installed HVAC system resulted inefficient to withstand the future climate conditions derived by the only variation of outdoor air temperature, pointing out the necessity to evaluate and design new active systems for varying weather conditions.
- The results regarding the future scenarios were limited by the intrinsic level of uncertainty within the study of forecasted future climate conditions.
- Finally, in the life-cycle cost analysis the internally ventilated option showed the best results, remarking relevant potential benefits also in a long-term perspective.

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