Optimising parameters for dynamic solar shading

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The integration of daylight analysis and building performance simulation together with optimisation techniques has been a problem for simulating adaptive building envelopes. This is currently only possible by combining different analysis tools and software as there are no conventional all-encompassing programmes available on the market. There have been recent advances in simulating adaptive façade technologies by combining EnergyPlus simulation software with MATLAB as well as GenOpt to perform optimisations. This work is adopting software frameworks developed by previous researchers, applying a similar method but using Grasshopper for Rhinoceros interface. The main goal of this study is to develop a tool that can help optimise the control of an external shading device by minimising the energy demand for cooling and lighting (during the cooling period of the year) as well as maximising the occupants comfort (daylight availability and room temperature). The simulation tool designed for this work integrates EnergyPlus (by means of Grasshopper plug-in Honeybee) for building performance simulation as well as Daysim (Grasshopper plug-in based on Radiance) to undertake daylight analyses and an optimisation plug-in for Grasshopper namely Octopus and OctopusLoop. The results of the optimized controlled external shading in comparison to static shading show significant improvements in energy reduction and occupants comfort.

Keywords: dynamic solar shading, optimization, daylight, SHGC, visible transmission, cooling and lighting energy

1 Introduction

The building envelope is a crucial part of the design of a building, it accounts for (solar) energy gains as well as energy losses. This is particularly evident for transparent building components as they allow daylight to partly enter the interior of the building depending on the size of the opening and the transparency and translucency of the material [24]. Adaptive facades can help improve the occupants' comfort whilst minimising building energy by means of dynamic adaptability of façade components and/or materials [30]. In office building design, glazed façades are highly popular but can cause thermal and visual discomfort due to large amounts of incoming direct solar radiation onto the façade [9]. Strategies such as active air-conditioning [31] alongside switchable/adaptive [10, 11, 14-16] glazing or internal/external solar shades [19, 30] are capable of simultaneously maintaining the temperatures at comfort level and regulate visual comfort for the users of the building.

Dynamic adaptive external shades were chosen for this analysis for various reasons. These include, a) external shades are a conventional method to reduce solar heat gain [7] in rooms, b) external shades are part of the architectural design in a lot of existing buildings as well new constructions and c) there are a broad range of control strategies for external shades such as manual, automated (timer-controlled) control strategies or external shades that work with sensors for temperature and/or radiation [34].

Research by A. Prieto [31] found that designers of office building façades prefer to use lightweight building components with high transparency that rely on active air-conditioning. Besides internal gains, solar radiation and high external temperatures are responsible for high cooling demands in office buildings [31]. A climate responsive building design could reduce energy demands for lighting, cooling and heating by up to 60% by means of orientation, insulation and the use of exterior shading [31]. The correct operation of shading devices can be crucial for the overall energy reduction [25]. Research on fixed and dynamic shading found that using an adaptive dynamic shading have the greatest impact on reducing overall annual energy demands as opposed to fixed shades or no shading at all [30].

Although very beneficial from an energy saving point of view, shading devices applied onto a window decrease the amount of daylight that will be transmitted through the window [30]. This will usually result in the reduction of the cooling energy use, but as the availability of daylight will be affected [20], this will likely result in an increase of energy demand for electrical lighting.

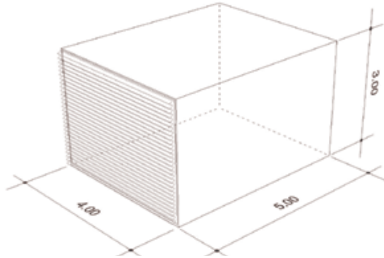
The present work examines an optimised control strategy of an external shading device on a south facing office room in Graz. It will be looking for the ideal set of parameters namely: Solar heat gain coefficient (SHGC) and visible transmission (Tvis) for every hour of the simulation period which is the hottest week during the year in Graz (first week of August).

The choice of a south facing room is to allow maximum daylight access inside the office whilst limiting solar heat gain. Undertaking this analysis required the creation of a bespoke building performance simulation tool that allows for dynamic adaption of the shading devices' angles during the simulation to control the simulation and optimise the shading by using Grasshopper for Rhinoceros.

The Energy Performance of Buildings Directive [8] requires all (non-government) new buildings must be nearly zero-energy buildings by the end of the year 2020. Dynamic adaptable façades inherit a large potential in contributing significantly to achieve the EPBD's goal.

2 Simulation Model

The study is conducted using a two people office room (4m x 5m x 3m) with one fully glazed south facing façade (95% glazing, 5% window frame) for the location of Graz/Austria (Fig. 1). The desired lighting level is set to 500 Lux (according to ÖNorm EN 12464-1: Lighting of work places pt.1 indoor work places [18]) constantly (illuminance on work-plane @ 0.75m height in the middle of the room) when the office room is occupied by one or more employees to allow good working conditions. There is one sensor point in the middle of the room at the height of an employee's desktop/work-plane (2m;2.5m;0.75m) for the daylight analysis (Figure 2). Work-plane illuminance has been used as a control strategy for external shading by Fiorito et al. [19]. The occupancy schedule is based on a typical austrian calendar year including holidays. Employees work 8 hours each day (monday to friday between 7am and 5pm) allowing for 1-hour lunch break. The physical values for SHGC and Tvis of combined window and blinds at various angles were calculated with LBNL Window [23]. The combined parameters for glazing and shading (SHGC, Tvis) are variable and part of the optimisation whereas the opaque part of the glazed façade consists of a wooden frame that is static (see Table 1 and Table 2,respectively, for physical parameters). The simulation model shall be able to switch between glazing only and different shading angles (0°-90°). The different shading angles represent different values for SHGC and Tvis (see; Figure 3 and Table 2).



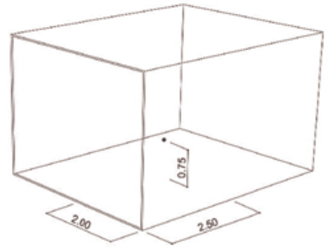


Fig. 1 Geometry of test cell (office room with south facade with 95% glazing)   Figure 2 Sensor for illuminance test in the office room

component	parameter
Glazing	Low-E Glass
U-Value	1.386 W/m2K
SHGC	0.635

Table 1 Physical parameters of the glazing

Software framework and simulation process

Wienold et al. [37] found that simulating daylight dynamically is greatly time consuming and even more so when shading devices are simulated and concluded that dynamic simulations that consider different shading positions are not possible with conventional software. He overcame some of the simulation issues in a later work using a 3- step simulation approach [38] separating the simulation process into three individual simulations using a database of results from the previously conducted simulation.

A more advanced simulation method to evaluate the performance of the adaptability of a façade/ façade component was used by other researchers who implemented the receding horizon (or model predictive) control technique [12, 13, 15, 22, 29, 32, 39] whilst also overcoming the thermal history management problem [2, 10, 28]. Receding horizon control [29] is a control technique that involves continually updating predictions and states such as temperatures that are involved in the decision making process for the optimisation/multi-objective optimisation problem [26] involving the implementation of algorithms to optimise the façade adaption in multiple steps [27].

Glazing/Blind type	SHGC	T
Blinds 0°	0,648	0,844
Blinds 15°	0,475	0,595
Blinds 30°	0,294	0,343
Blinds 45°	0,126	0,114
Blinds 60°	0,073	0,047
Blinds 75°	0,041	0,012
Blinds 90°	0,04	0

Table 2 Parameters for window with different blind configurations according to WINDOW 7.6

In order to integrate building energy performance with daylight analysis [19] and to overcome current building performance software restrictions to evaluate the performance of adaptive facades [12], a bespoke simulation tool was developed using the software add-on Grasshopper (GH) [3] for Rhinoceros for this study.
The concept of the simulation was adopted from previous research such as Favoino et al. using an evaluation, an optimisation and a coordination layer [12].
The tool consists of Honeybee [33] a plug-in for Grasshopper, to implement EnergyPlus Version 8.8.0 [4] to run the building energy performance and Radiance based DAYSIM [21] for daylight analyses. Ladybug [33] was used to read and analyse the epw- weather file [5] for EnergyPlus [4]. These GH-add-ons form the evaluation layer to assess the performance of the shading control for this study. In EnergyPlus The EMS tool (Energy Management System) [6] was used to simulate the adaptive behaviour of the shading and hence to allow for different physical parameters during the simulation. The optimisation layer is composed of the Grasshopper plug-in Octopus [36]. Octopus was used for the optimisation process. Furthermore OctopusLoop [35] was used to re-integrate optimised preliminary results of the preconditioning, into the following optimisation loop 2 and hence allow incorporating the thermal history [17]. The coordination layer is set up by components that are part of the GH interface.

Simulation process The simulation runs in two circles or loops. Loop 1 calculates potential results for energy demands (cooling, lighting) and takes current weather data (external temperature in °C, solar radiation W/m2), internal temperature (°C) and (day-) light conditions (Lux) (inside the office room) into account. The best results for the façade parameters (shading angles) of the 'pre-selection' are stored and used in loop 2 where the actual optimisation process is taking place. The (stored) parameters (shading angles) of the 'pre-selection' will be fed into loop 2 where the (multi-objective) evolutionary algorithm (SPEA-2 core algorithm [36]) of Octopus will pick the combination of the best parameters (shading angles) for the glazing and shading. The results will then show that at different times of the day, different properties of the façade parameters are required to reduce energy demands (especially cooling and lighting) and to maintain the user's comfort. The simulation process is rather time consuming for the afore-mentioned reasons. Therefore, the simulation period was reduced to one week that is the hottest week in Graz during the annual cooling period. The optimisation however was undertaken on an hourly basis [14].

$$\min \begin{cases} f(x) = E_{tot} = E_{cool} + E_{light} \left[\frac{kWh}{m^2 y}\right] \\ X(t) = (g - value(t), \tau_{vis}(t)) \end{cases} \qquad \text{Eq. 1 cost function}$$

The cost function of the optimisation problem to be solved is as following: The model has previously been validated undertaking various simulations for the adaptive façade research project at Graz University of Technology. [1]

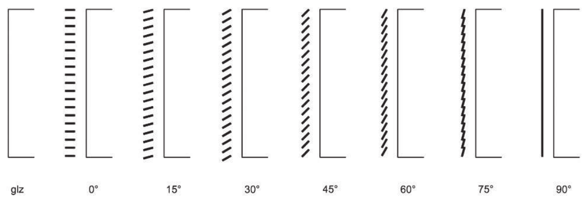
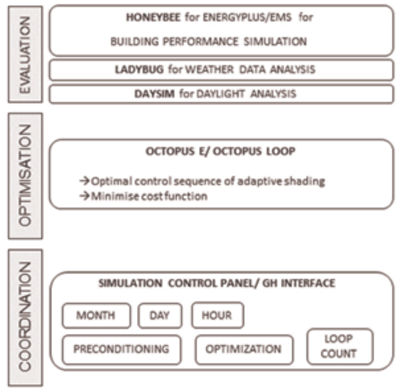


Figure 3 Glazing and straight blinds configuration



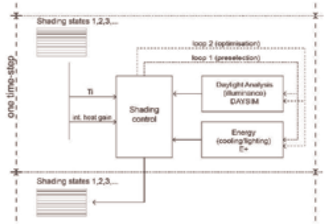
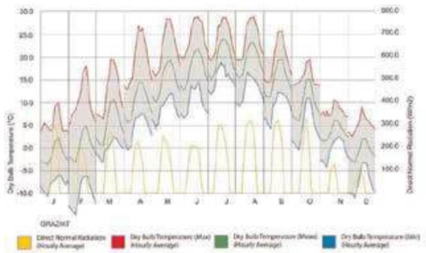


Figure 4 simulation framework

Figure 5 simulation approach

Weather data The weather file (*.epw) [5] is retrieved from the US-government website for EnergyPlus for the location of Graz/Austria and data for the temperature (mean, maximum and minimum temperature in °C) and solar radiation (direct and diffuse radiation) are used within the simulation environment.



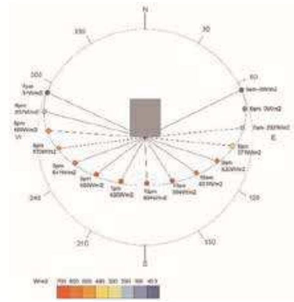


Figure 6 Weather data Graz (Temperature and radiation)

Figure 7 Sunpath and sun vectors in Graz on 6th August show the amount of direct solar radiation at each hour of the day (5am- 7pm)

3 Results

Prior the optimisation simulation, (static) simulations for each shading state including no shading at all were undertaken for reference. The results shown in Table 3 and Figure 8 show an expected decrease of cooling energy and a slight increase in lighting energy, respectively, with increasing closure of the shading slats in front of the glazing for the simulation period of the hottest week in Graz (3rd to 9th August) for a south-facing façade.

The cooling energy drops at two states significantly, when the blinds start closing at 15° and when they block the sun vectors efficiently at 45° angle of the blinds. The cooling energy keep on decreasing the further the shading is closed but the difference is much less (state 45° to 90°) compared to blinds at 0° to 30° angle.

The increase in lighting energy is linear but not as dramatic as the cooling energy for the hottest week. There is a clear increase in energy demand from 45° closure onwards to 90° when the blinds are completely closed. The best results however are achieved with the optimised shading control achieving energy savings for cooling and lighting of close to 42% compared to closed blinds at 90° (static). What these figures are not representing is the quality and quantity of daylight inside the office room during active occupancy. Table 4 gives an example of daylight quality of one representative day during the hottest week at 9am, highlighting the intense morning sun (glazing only) with potential glare probability (not examined within the scope of this work) and no useful daylight at all when shades are completely shut (blinds closed at 90°). Not only does Table 4 emphasise different daylight qualities at different shading angles, but it also clearly shows the potential of a sophisticated shading control that would allow enough natural daylight to penetrate the office room whilst limiting solar heat gain to heat up the room beyond the comfort level of the occupants.

Considering a cooling period for Graz from April to September (compare Figure 6, Figure 7 and Figure 10) the overall energy savings for cooling and lighting for an office room with a south-facing façade with a dynamic adaptive solar shading will most likely increase. Figure 9 represents the schedule of the optimised shading control showing the degree of opening of the shading slats at every hour of the hottest week in the summer in Graz with internal and external temperatures. The internal temperatures (TZone in °C) are fairly stable and do not follow the outside temperature extremes. The shading schedule is adequate to the external temperatures and the shading slats are more closed with increased temperatures. The schedule during the working week (Monday-Friday) ranges mostly between 45° and 90° with few exceptions. Only on the weekend the blinds are almost fully closed at all times. This result may not show a dramatic improvement for scheduling external shading devices but proves 1) that significant energy savings with optimised schedules are possible and 2) that the proposed simulation framework is running as suggested. The actual quality of the proposed software needs much further investigation such as a) running an annual analysis to present energy demands not only for cooling and lighting but also heating energy. Further aspects of the office's user must be undertaken like a) visual comfort, b) DGP (daylight glare potential), c) UDI (useful daylight illuminance) to comprehend the influence of optimised adaptive façade parameters for transparent components.

Glazing/Blind type	Cooling (kWh)	Lighting (kWh)
Glazing	84,9	5,1
Blinds 0°	86,4	5,1
Blinds 15°	61,1	5,1
Blinds 30°	47,1	5,1
Blinds 45°	35,3	5,2
Blinds 60°	28,5	6,0
Blinds 75°	25,3	7,4
Blinds 90°	25,1	7,8
Optimized shading	17,18	1,8

Table 3 Energy demands for the hottest week in Graz (3rd – 9th August)

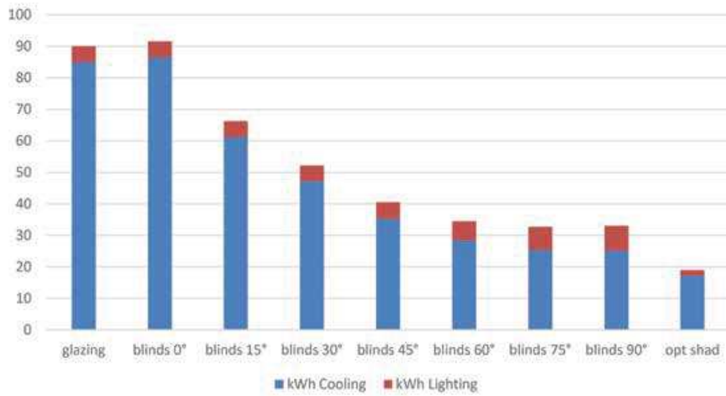


Figure 8 Energy demand for cooling and lighting for south-facing office room in Graz (hottest week 3rd august to 9th august)

Another aspect that has been neglected within this study is the user acceptance of adaptive shadings. This study shall solely focus on 1) a strategy/simulation framework to evaluate adaptive façade components (shading device in this case) and 2) figure out the potentials of adaptive façades/ façade components and possible energy savings with 3) control strategies.

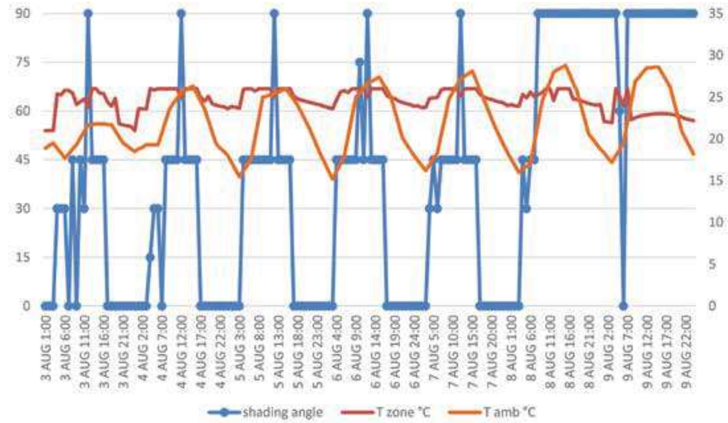


Figure 9 Shading schedule for south facing façade in Graz (3rd to 9th august)

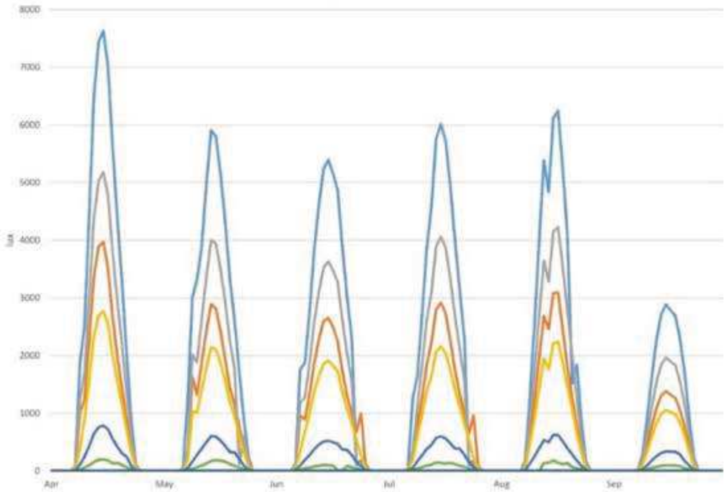


Figure 10 Lighting levels inside the office during the cooling period

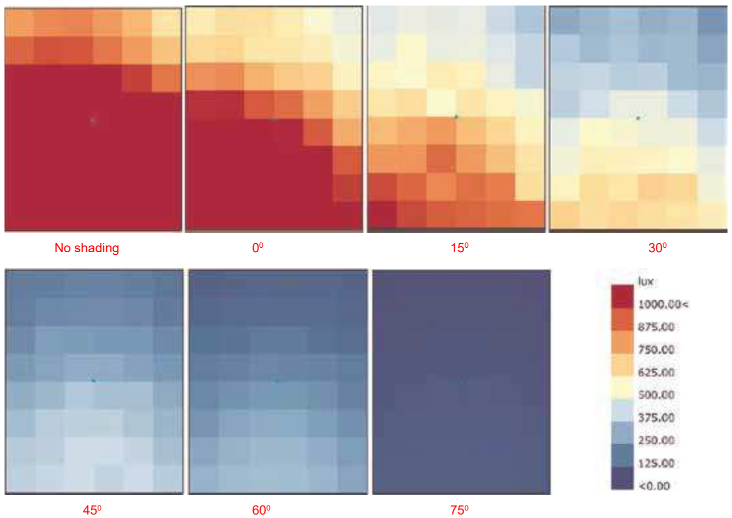


Table 4 Illuminance on 6th August @ 9am at various shading angles

4 Discussion

The physical parameters for SHGC and Tvis of the combined glazing and shading at various angles could be identified using LBNL window software. Based on these parameters the thermal building simulation combined with daylight analyses were conducted to find an optimal control

strategy for the blinds. Further thermal simulation shall be conducted on a monthly basis as well as on a yearly basis to fully understand the potentials of variable and adaptive façade parameters. Another aspect that should be considered is to take weather forecasts into account in order to compare a conventional 'real-time' optimization process as opposed to an optimized 'forecast' scenario. This analysis was based purely on hot weather (cooling period), where unwanted solar gains onto the south façade play an important role. The adaptability in a cold weather and the effectiveness of an adaptive façade in a cold climate should be further investigated to allow serious statements about the energy saving potentials of varying the g-value and visible transmission of a glazed façade. Control strategies for external shadings using a software framework that adopts optimisations should be further investigated to fully comprehend the potential of adaptive façades/ façade components and to evaluate optimal schedules and time horizons for the adaptability of the façades/ façade components. The annual analysis of the variable façade parameters would further allow to understand what the optimal time steps are to change a façade parameter and hence would help designers develop facades that could adapt to the changing seasons during the year or changing weather during the day. The focus of the present work lay on an optimised control strategy which should be compared with other control strategies such as control rule based strategies to evaluate the functionality, energy savings and effectiveness of the chosen technique.

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Modelling Envelope Components Integrating Phase Change Materials (PCMs) with Whole-Building Energy Simulation Tools: a State of the Art

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Building envelope systems that integrate Phase Change Materials (PCMs) are solutions aimed at increasing the thermal energy storage potential of the building envelope while keeping its mass reasonably low. Building envelope components with PCMs can be either opaque or transparent and can be based on different types of PCMs and integration methods. In opposition to conventional building components, these elements present thermal and optical properties that are highly non-linear and depend to a great extent on the boundary conditions. Such a characteristic requires the system development and optimisation process during the design phase to be carried out with particular care in order to achieve the desired performance. In this paper, a review of the existing modelling capabilities of different building energy simulation (BES) tools for PCM-based envelope components is reported, and the main challenges associated with the modelling and simulation of these systems through the most popular BES tools (among them, EnergyPlus, IDA-ICE, TRNSYS, IES-VE, and ESP-r) are highlighted. The aim of this paper is to summarise the evidence found in the literature of the latest development in the successful use of BES to replicate the thermal and optical behaviour of opaque and transparent components integrating PCMs, in order to provide the community of professionals with an overview of the tools available and their limitations.

Keywords: Phase Change Materials, building envelope, modelling, simulation

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