122: Intelligent facades in hot climates: energy and comfort strategies for successful application

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Abstract

Facades are crucial to energy consumption and comfort in buildings. Incorporating intelligence in their design is an effective way to achieve low energy buildings. However, careful planning must be involved to reach satisfactory savings and user acceptance. The article examines the design process itself, as key to produce energy efficient buildings. Three strategies are examined: the first is dependence on active systems and element performance, the second implements intelligent passive design strategies only, while the third combines passive design strategies with early integration of active elements. Their impact on energy performance and visual comfort are compared. Although early combination of active elements and climatic principles is beneficial, there are some limitations to carry it out efficiently, among them ineffective design tools. A design tool that suggests good starting solutions is presented, which takes into account how architects work during conceptual phases. Practical guidelines are provided for design of intelligent facades in hot climates. Relevant climatic principles are stated, together with considerations on elements, users and facade operation.

Keywords: intelligent facades, hot climates, low energy buildings, design tools, guidelines

1. Introduction

The scope of intelligence in buildings has expanded from facility management to means for achieving low or zero energy buildings. An important part of the intelligent building is its facade, both from image and energy performance point of view. It is not just an implement to reduce energy consumption; it should also provide user comfort according to climate demands.

However, most of the intelligent facades in use today are located in regions with predominantly cold climates. Accelerated demands for modern built space in regions with hot climates, new global energy consciousness and fast technological transfer, lead to think that intelligent facades cannot just be copied. Their behaviour must satisfy specific requirements of the climate where they will perform.

An intelligent facade is a complex product that self-adjusts through its components (active or passive) to changes produced by its surroundings or interior [1]. Intelligent facades cannot be seen separate from the building as a whole or from other project factors.

The article examines design strategies for intelligent facades in hot climates based on decision timing, using an energy and visual comfort approach. It presents a design assistant tool that helps to choose good starting solutions among different facade and element combinations, based on principles of an energy code for hot climates. The final section provides practical guidelines to carry out these strategies.

2. Strategies for the Design of Intelligent Facades

2.1 Design Process and Influence on Energy Performance

As the main interface between interior and exterior, facades contribute up to approximately 36% of energy consumption in hot climates [2]. Therefore, special attention must be given to their design, components and operation. However, one factor frequently overlooked in the creation of energy-efficient buildings is the design process itself. This section examines how decisions made during different stages of an intelligent facade design process can affect overall energy consumption and performance.

Design method specialists usually divide the design process into different stages. Although specific names vary, they can be classified into early and late stages. Early stages comprise conceptual development and task clarification, while later ones deal with detail design and production [3].

The large number and complexity of components available for intelligent facades make difficult the selection task. At the same time, design teams might be faced with problems unrelated to energy savings such as defining building image or views.

Therefore, two situations could arise: the first is where the designer decides to depend on active element performance, delaying selection until later design stages or even construction. The second is where the designer considers from conceptual phases active facade elements while at the same time taking into account climatic building principles such as those summarized in Fig. 5. An "intermediate" situation is designing with climatic principles using adequate passive strategies but without active elements.

Product development research has shown that decisions taken during early stages will determine if the final output will accomplish its objectives or not [4, 5]. Our research tested if this principle would hold true for energy and comfort performance of intelligent facades. Using EnergyPlus, parametric variations were applied to an office module of area 50sqm. The module represents part of an existing building located in the coastal plain of Haifa, Israel (32.5°N, 35°E), where local climate is defined as Mediterranean of warm summers and mild winters. Parametric variations and their codes are detailed in Table 1.

Table 1: Parametric variations used for comparison and explanation of codes for figures 1 to 3. **Bold** represents variable changed from previous alternative.

	Case	Orient.	Code
Active features only	1	W	w-Cl-Ib-on (basecase)
	2	W	wW-Cl-**IbR**-on
	3	W	w-Cl-Ib**GR**-on
	4	W	w-Cl-**Eb**GR-on
	5	W	w-Cl-**Ib**GR-on-**aV**
	6	W	w-Cl-IbGR-**st**-aV
	7	W	w-**Le**-IbGR-st-aV
	8	W	w-Le-**Eb**GR-st-aV
Passive design only	9	W	w-Cl-Eb-st
	10	W	w-Cl-Ib-st
	11	W	w-Cl-Ib-st-**nV**
	12	W	w-**Le**-Ib-st-nV
	13	W	w-Le-**Eb**-st-nV
	14	**S**	**s**-Le-**==**-st-nV
	15	S	s-Le-**Ib**-st-nV
	16	S	s-Le-Ib-st-nV-**Ls**
Passive design +active features	17	S	s-Le-**IbR**-st-nV-Ls
	18	S	s-Le-Ib**GR**-st-nV-Ls
	19	S	s-Le-IbGR-st-nV-Ls **[10m depth]**
	20	S	s-Le-Ib**GR**-Di-aV-**HsLs**
	21	**W**	**w**-Le-IbGR-Di-aV-HsLs
	22	**N**	**n**-Le-==-Di-aV-**HsLl**
	23	N	n-Le-==-Di-aV-**====**

Glazing: Cl= double glazing clear (3mm+6mm+3mm,VT=0.81, SHGC=0.76)
Le= Low emissivity glazing (6mm+6mm+6mm, VT= 0.68, SHGC= 0.42)
VT= visible transmittance; SHGC= shading glazing coefficient

Blinds: Ib = internal blinds; Eb = external blinds
Activation: GR = glare; R = solar radiation

Light Control: On = Always on; st = Stepped; Di = Dimmer

Ventilation: aV= Fan with setpoints; nV = natural driven night ventilation

Lightshelves: Ls = 1.0m single; HsLs = 0.5m upper 0.5m lower; HsLl = 0.5m upper 1.0m lower

Three variations series were evaluated, each representing a design strategy. In all of them the basecase has a single opening facing the sea (west), with double glazing. Basic module depth is 7m, except for case 19, which is 10m deep to test building depth influence. It has no shading devices and artificial lights are left on during all working hours.

Active elements used in the first and third series included glare and radiation-activated blinds, deploying to a fixed angle. Light controls were stepped lighting and dimmer. Ventilation was addressed with fans having temperature setpoints and timers that allow windows to open for natural ventilation. Glazing was changed to low-emissivity in certain cases.

The series "active features only" represents a design team incorporating active elements at very advanced stages of the design process, depending only on their performance. Active elements are glare-activated blinds (internal or external) with fan ventilation in some cases.

Series "passive design only" represents a situation where good passive building principles were used throughout the design process. Elements in the series are not dynamic but only manual night ventilation was allowed.

"Active features and passive design" represents careful climatic planning from early stages that incorporates adequate passive strategies combined with suitable active elements. Cases 20 to 23 are optimized solutions developed for the specific climate type in the framework of the Israel Energy Code (IEC) [6].

The series were tested for energy consumption and visual comfort. Results are shown in Figs. 1, 2 and 3 although visual comfort is presented only for selected cases and dates.

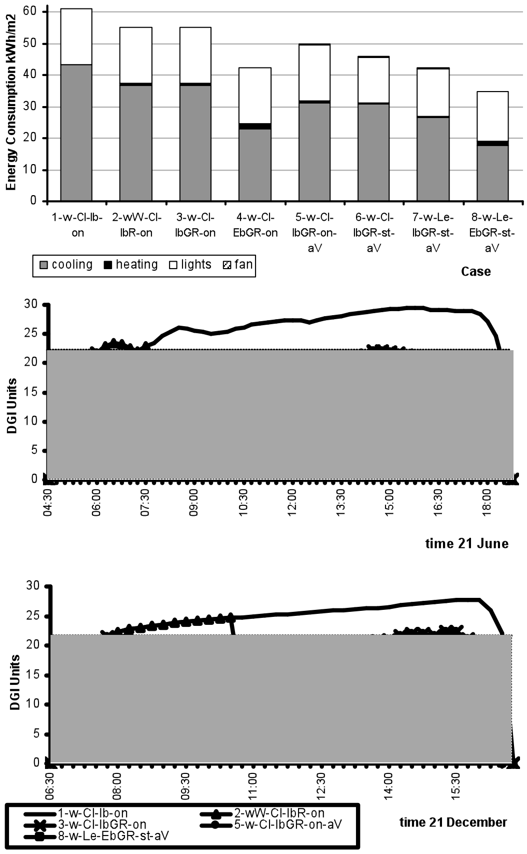


Fig 1. Active features only: Yearly energy consumption and daylight glare index for 21 June and 21 December. Haifa, Israel

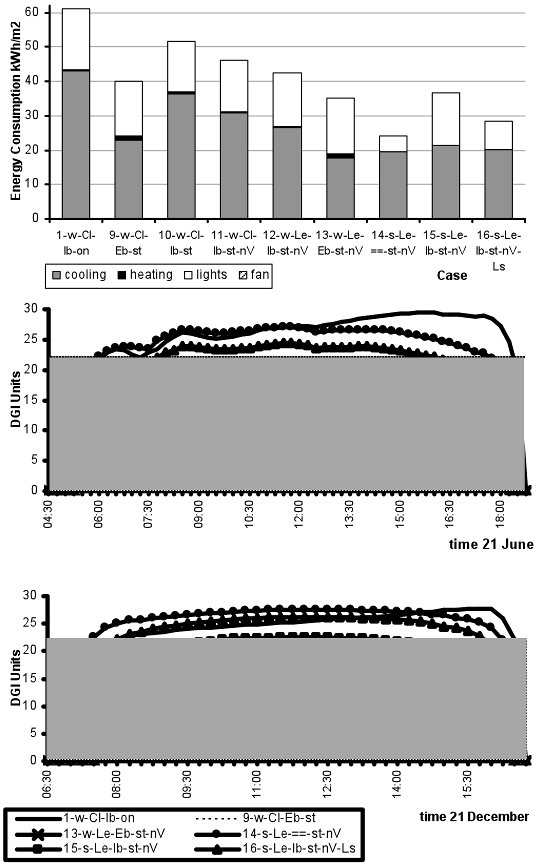


Fig 2. Passive design only: Yearly energy consumption and daylight glare index for 21 June and 21 December. Haifa, Israel

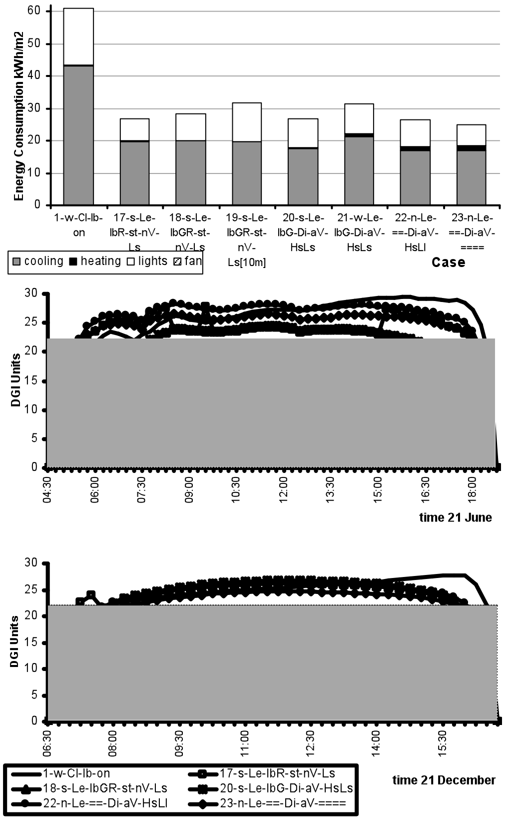


Fig 3. Active features and passive design: Yearly energy consumption and daylight glare index for 21 June and 21 December. Haifa, Israel

As seen from the simulation results, "active features only" (Fig. 1), which represents dependence on performance of active features, had the smallest energy savings, from about 60 kWh/sqm in the basecase, to around 35 kWh/sqm (case 8). Visual comfort, however, stayed within acceptable levels at both test times. Active features in the series were configured to achieve visual comfort (since there was no other way for the users to protect themselves from glare) and did so successfully.

"Passive design only" (Fig. 2) had the largest energy savings from the three series, from approximately 60 kWh/sqm per year (basecase) to around 24 kWh/sqm per year (case 14). However, savings are not consistent in all situations and results are intermediate when glare is considered. This series presents disadvantages such as lack of user control and that fixed devices affect views, which was the reason to start with a west orientation. Also, the lowest energy consuming module in the series is oriented south, which might be seen as a departure from the potential project-marketing feature.

Combining passive design strategies with active features (Fig. 3), represents an integral planning strategy. Adequate active elements and passive strategies are chosen from early design stages. The series provides consistent energy savings when correct strategies are employed, together with predictable visual control behaviour. It shows the largest number of cases with low yearly energy consumption. However, all design decisions affect how large these savings will be. This is seen, for example, in case 19 where an increase in depth means also an increase in energy consumption due to increased electric-lighting use [5].

2.3 Limitations on Early Stages

Simulation results show that considering adequate elements and strategies during early design phases brings largest energy savings. In addition, at this point of the process there is more flexibility to bring changes to the design brief and make decisions with most impact [3].

However, there are many limitations faced by designers during this step, such as the constant search for a design objective to follow. It is carried out mainly using an iterative black box method fed by incoming information, design principles and mental proposals that are sketched using simple graphical representation [7]. These schemes are translated to information understandable by other professionals only until when measurable data can be determined [8].

This makes existing design and simulation tools to offer, in general, few adequate help in developing intelligent facades from early design stages. At most, they can digitalize sketches [9] and require exact and detailed data unknown and irrelevant to early design stages (such as fan air speed, insulation layers, etc). They are geared to evaluate finished alternatives, not to suggest, develop and assess different schematic options.

In particular, for projects in which the designer reaches extremes to his or her expertise, there are few criteria to base on for steps to take after product conception.

3. NewFacades - Assistant for Design of Intelligent Facades

3.1 Description

It is extremely difficult to propose an initial idea that is also "the" optimal or near-optimal configuration to a given problem such as achieving zero or low energy consumption. Even having energy consumption estimates can be difficult due to lack of accurate data in the early stages. In most cases a "good" solution is achieved only after specialized testing and trial and error. This is a setback when schedules are tight and there is an ever-growing array of possible active devices to be evaluated.

These factors, together with limitations described for early design stages, lead us to develop a solution-suggesting tool called "NewFacades". Based on basic architectural ideas or concepts, it proposes intelligent facade combinations together with energy and glare evaluations for a given situation. It follows the integral planning strategy, where elements are seen as part of a whole. Therefore, the tool also suggests elements beyond the facade that influence envelope performance, such as night ventilation type and light controls for the space. Both the solution-suggestion and integral approach are missing in design tools available today.

The proposed tool translates data and schematic concepts easily understood by all architects from the beginning of the project. Design concepts included are: location (expressed as a list of cities), main facade or terrain orientation, building's morphology, usage, project surroundings, transparency of the envelope and degree of automation to be incorporated (which relates other project elements such as available budget). It does not require an accurate input and is easy to use, in contrast to existing tools that in general are hard to use [7].

Alternatives are formed on-demand by using principles abstracted from the prescriptive section of the Israel Energy Code [6], to achieve the highest marks it can award. Although the proposed IEC has both a prescriptive and performance approach, it was decided to use IEC's optimized prescriptions which are based on economic-energetic criteria [10]. This prevents the tool looking for a single "best" solution, which would not enrich the design process. However, principles of other energy-based building codes can be incorporated as well.

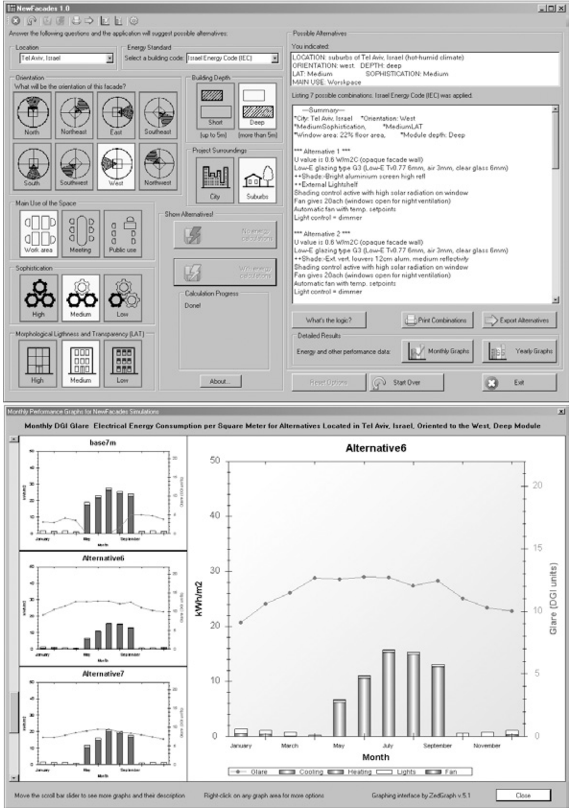
EnergyPlus, a late-stage energy-modelling program, is used to evaluate each alternative. All possible suggestions are then displayed in a catalogue style, which also presents total energy consumption outlook and visual comfort performance.

The tool has a library of predefined active and passive element characteristics that are applied when relevant conditions in the energy code allow. At the moment general items used in active ways are included, such as commonly available glazing types, shading elements and blinds. But it can be expanded with newer, more sophisticated products as they appear in the market.

3.2 Application Example

Fig. 4 illustrates the tool interface for user input and part of the graphical results that can be obtained. The hypothetical project illustrated in the figure is located in the coastal strip of Israel (Mediterranean climate of warm summers and mild winters). As described in section 2, the facade under study is for an office building, west-oriented for Mediterranean Sea views and marine-breeze.

Initial ideas are as follows: windows should be as large as possible, in order to take advantage of views. However, limited initial and maintenance budget restrict automation to a minimal level. Building depth is proposed to be short (approximately 6m). The designer indicates these data in the relevant input areas and can ask for an energy assessment or just generation of a list of possible alternatives. When energy assessment is required, graphical output is displayed as illustrated in Fig. 4.



Answer the following questions and the application will suggest possible alternatives:

Location: Tel Aviv, Israel

Select a building code: Israel Energy Code (IEC)

What will be the orientation of this facade?

Energy and other perfomance data:

Calculation Progress: Done!

You indicated:

```
LOCATION: suburbs of Tel Aviv, Israel (hot-humid climate)
ORIENTATION: west.   DEPTH: deep
LAT: Medium          SOPHISTICATION: Medium
MAIN USE: Worskpace
```

Listing 7 possible combinations. Israel Energy Code (IEC) was applied.

```
    ---Summary---
*City: Tel Aviv, Israel    *Orientation: West
*MediumSophistication,        *MediumLAT
*Window area: 22% floor area,        *Module depth: Deep

*** Alternative 1 ***
U value is 0.6 W/m2C (opaque facade wall)
Low-E glazing type G3 (Low-E Tv0.77 6mm, air 3mm, clear glass 6mm)
++Shade:-Bright aluminium screen high refl
++External Lightshelf
Shading control active with high solar radiation on window
Fan gives 20ach (windows open for night ventilation)
Automatic fan with temp. setpoints
Light control = dimmer

*** Alternative 2 ***
U value is 0.6 W/m2C (opaque facade wall)
Low-E glazing type G3 (Low-E Tv0.77 6mm, air 3mm, clear glass 6mm)
++Shade:-Ext. vert. louvers 12cm alum. medium reflectivity
Shading control active with high solar radiation on window
Fan gives 20ach (windows open for night ventilation)
Automatic fan with temp. setpoints
Light control = dimmer
```

Move the scroll bar slider to see more graphs and their description

Right-click on any graph area for more options

Graphing interface by ZedGraph v.5.1

Fig 4. NewFacades, an intelligent facade design assistant for conceptual phases: Input area and sample monthly energy and visual comfort results for a west-oriented case in Tel Aviv, Israel.

3.3 Results and Connection to Further Design Stages

Results given to the user include a list of alternatives in which active and passive elements are detailed. It also recommends night ventilation and light controls. Their monthly/annual energy consumption and visual comfort is expressed in graphical form, in order to help designers choose the most convenient alternative based on other project limitations.

The tool offers the advantage of allowing additional refining and development of one or more facade combinations, through file outputs compatible with energy modelling programs like Energy-Plus. This can connect the program with further design tools such as COMFEN [11], and help designers enter into the next steps of the design process.

4. Energy and Comfort Guidelines for Intelligent Facade Design in Hot Climates

4.1 Climatic Strategies for Hot Climates

It was demonstrated that early design decisions integrating early climatic principles and active elements result in consistently high energy savings. Therefore, any active or passive facade element must follow the climatic strategies summarized in Fig. 5. This section provides practical guidelines to carry them out.

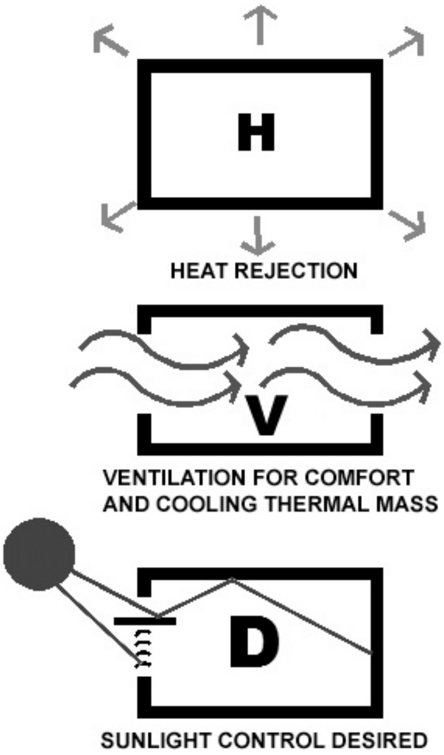


Fig 5. Climatic strategies that must be followed by intelligent facades in hot climates

Heat rejection: Particularly in public buildings, for most of the year, building envelopes must exclude external heat. However, there must be means to allow heat storage or generation during cold periods. Heat exclusion can be achieved, for example, with elements such as: adequate orientation, insulation, and window size as well as fixed or dynamic shade elements deploying at a given radiation level. These elements can also help to achieve heating savings if winter time requirements dictate so.

Ventilation: Must be provided to control relative humidity in hot-humid climates or correct it by evaporation in hot dry-ones [12]. It helps to achieve internal comfort, and to cool thermal mass of a building. Depending on local climate conditions, relative humidity can be controlled either by mechanical room ventilation or night ventilation. This also allows a high number of air changes to be achieved, if necessary.

Natural night ventilation offers the least energy option to cool thermal mass [13]. As seen in Figs. 1, 2 and 3, implementing artificial night ventilation (for example, by timed window openings combined with fans), reduces total external energy used for cooling a building in summer.

Sunlight control: In order to provide visual comfort and at the same time reduce heat gains, sunlight must be controlled and daylight must be re-directed into the space. This can be done through a variety of fixed or active devices. For example: overhangs, shades, anidolic concentrators and lightshelves [14, 15]. However, care must be taken into their design and configurations to avoid becoming sources of glare [14]. By using advanced electrical controls (such as dimmer), artificial lighting is used as a supplement to natural light for performing visual tasks. This also helps to reduce cooling demands in a room.

Daylight control offers opportunities to incorporate innovative active elements and materials, such as automatic blinds with special reflective profiles or holographic films [15].

4.2 Design Strategies

As seen in this paper, the most effective energy savings are achieved by using integral planning practices. Intelligent facades must be seen as part of a whole and not as a way to achieve prestige design. This involves considering, from conceptual design stages, adequate climatic strategies and elements that will help them to be carried out.

In this context, it is not desirable to depend on the performance of a single element. A useful design approach is to see intelligent facade components as part of a process of perception, reasoning and action [16]. Although the scope of design tools for early stages is still under development, those that can evaluate changing reactions over time have to be preferred [17].

4.3 Functional Recommendations

Operational and behavioural aspects must be considered to provide a product acceptable to end users and facility both in its daily use and maintenance. This will provide more assurances that facades will work as expected.

Users must have always the possibility to control and override settings. Operation interfaces must be understandable, simple to use and give a comprehensive summary of what is happening and the effects of actions.

In a similar subject, elements must be configured in ways that do not annoy users. For example, adding response delay in dimmers or radiation sensors can be useful to avoid luminaries flickering or blinds opening and closing without apparent reason [18]. Using night ventilation and fan speed must take into account factors such as air filters (for dust, pollution, etc) and avoid causing undesirable drafts.

Budget available for the project and other priorities might dictate which kind of controls to apply. Using dimmer achieved large reductions in the active elements and passive design series. Nevertheless, a related control, stepped lighting, can also be successfully implemented by adequate planning and assignment of light switches [19].

It must be remembered that systems tend to wear down with time and need to be replaced. Even if maintenance programs are in place, systems that are too complicated or unusual might eventually be abandoned due to lack of spare parts [5].

Just as energy savings cannot depend only on the performance of a single element, facade operation must not depend on electronics or components that in case of failure disrupt even basic operation. This is another justification to incorporate passive design principles as part of integral planning.

5. Conclusion

Intelligent facades must be seen as an essential part of a zero or low energy building, and not as a separate product. Integration begins from the design process itself, by early incorporation of adequate climatic principles and considering elements that will fulfil them. Choosing adequate strategies later in the process is difficult or impossible.

A large variety of components are available, but each case will dictate their appropriateness. Energy performance cannot depend on one component alone. Each situation will determine which climatic strategy has to be carried out more actively than the rest in order to achieve high energy and comfort performance. Additionally, user interaction with automated built environments has to be carefully studied in order to predict realistic behaviours.

Design tools as provided in this work can help to achieve good starting solutions and incorporate intelligence in all stages of facade design.

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