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# Dynamic facades, the smart way of meeting the energy requirements

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**Abstract**

The paper describes an innovative dynamic façade system, developed in cooperation between two industrial companies, the Danish Building Research Institute and Aalborg University, Denmark. The system, named Energy Frames, is a newly developed industrially produced façade system based on the experiences of a number of specially designed solutions for significant individual buildings all over the world. Energy Frames is a modular framework-based façade system that snaps on the outside of the window frames. The frames can be moved horizontally or vertically in front of the window and is suitable for both new and existing buildings, solving the fundamental functions of the façade: solar shading, daylighting control, dynamic façade U-value, natural ventilation, and noise reduction.

Through the use of thermal building simulation tools as well as full scale measurement of the façade system, the energy saving potential is investigated showing the benefits and the challenges of working with dynamic façades in research and practice.



*Keywords:* Dynamic façades; Active building envelope; Intelligent facades; Advanced façades; Integral building envelope performance

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## 1. Introduction

Building designers and owners have always been fascinated with the extensive use of glass in building envelopes. The façade is a means of communicating an image of prestige and power. Glass is a unique building material which gives the designers great opportunities for creating a building design with aesthetic appeal of elegance, transparency and lightness that no other material can offer. The transparency increases interaction between the external and the internal environments and from an architectural point of view there are many benefits of the transparent envelope solution concerning daylight, view to the outside, etc. The innovation in glass technology over the last 20-30 years has pushed this development and many new sophisticated approaches are being developed which will add more features and opportunities to the use of glass as façade material, e.g. electrochromic glazing and glass with integrated light emitting diodes (‘communicating facades’). Ironically, the highly glazed buildings have often been associated with ‘green buildings’ or ‘sustainable design’ - in spite the fact that these buildings in practice very often encounter severe indoor climate problems and large energy bills.

The design of the facade has enormous significance for both indoor climate and energy consumption as there are many energy-flows both ways over this boundary between the external and internal environments. The main role of the façade is to protect the indoor environment from the outdoor environment and the optimization of this function includes control of (leaving out many other functions as noise, security, etc.):

- Heat transmission from inside to outside
- Solar load from outside to inside
- High utilization of passive solar gains
- High utilization of daylight
- Protection against glare from outside
- Air flows between inside and outside (both ways)
- Allow for a view to the outside
- Allow for privacy

Optimization of the function of the façade can be expressed as *to provide (thermal and visual) indoor comfort for the occupants (during the time they are present in the building or the space) at the lowest possible total consumption of energy*. The static glass facade will not be able to give optimal performance except for a few short periods during the year. For offices and commercial buildings it is quite obvious that it would be optimal if the envelope systems respond sensibly to the changes in the exterior climate and adjust solar gain, daylighting, heat loss, ventilation, and venting to the changing needs of the occupants and the building. This is the background for the development of the dynamic façade system described in this paper.

## 2. Energy requirement in building regulations

With the adoption of the recast EPBD in 2010, Directive 2010/31/EU [1], EU Member States face new tough challenges. Foremost among them, future new buildings should be Nearly Zero Energy Buildings (NZEB). These increasingly stronger requirements for energy efficiency of buildings call for innovative solutions that can reduce all parts of the energy consumption. Figure 1 shows the changing energy requirements in Denmark [2] where the demands (red lines) are expressed as a limit for total primary energy consumption in kWh/m² per year, with a limit of 25 kWh/m² per year in 2020. The figure also illustrates the typical constituents of the consumption (for a typical/model office building) divided into heating, cooling, ventilation, lighting, and miscellaneous when using conventional passive façade technologies. The figure indicates that in the North European climate the energy for heating constitutes the largest part of the total consumption. Fulfillment of the requirements must be documented through calculation with a quasi-steady-state method, Be10 [2], under a number of standard assumptions. The 2015 column illustrates how much the energy needs can be reduced by using traditional passive facades in a typical office building, i.e. the requirements can hardly be reached without introducing some form of sustainable energy supply, e.g. PV panels. The last column in the figure shows the great challenge of the 2020 energy requirement, which calls for dynamic façade technologies or other significant measures, e.g. local sustainable energy production.

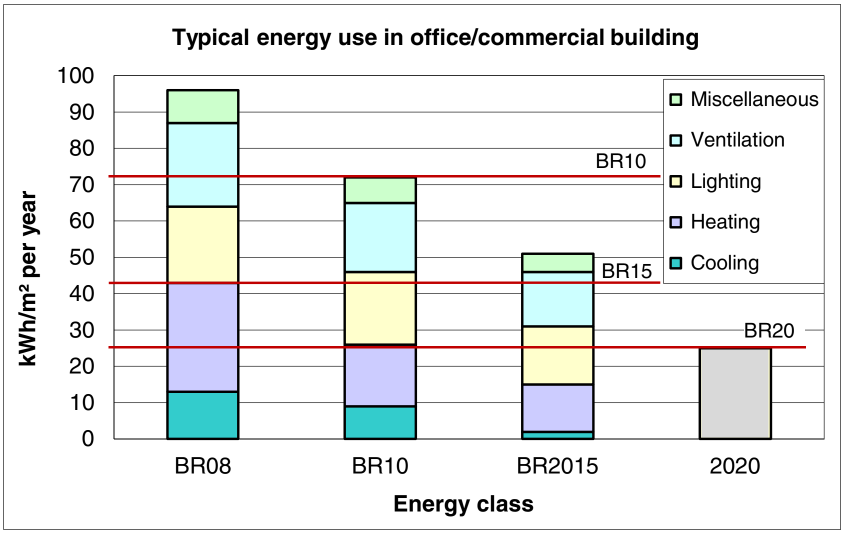


Figure 1. Energy requirements (shown by the horizontal lines) in the Danish building regulations from 2008 till 2020. The first three columns illustrate the typical constituents of the total energy consumption in offices or commercial buildings when using passive façade technologies. The last column shows the 2020 energy demand, which can only be met by dynamic technologies (or by introducing sustainable energy supply). The energy demands must be documented by a standard calculation method, Be10, based on EN ISO 13790 [3].

Since the façade plays the most significant role for the energy consumption of the building a major challenge is to design the façade for minimum energy demand for heating, cooling, ventilation and lighting through maximum exploitation of the natural energy flows offered by the external climate. This is exactly the strength of the dynamic façade. Dynamic façade cover technologies which are able to control the heat loss and access for daylight and solar gain when beneficial. The ideal shutter system combines insulation and solar shading to give maximum possibility for adaptation to the current exterior climate and user needs. The smart way of controlling the façade technologies is achieved using Energy Frames and initiates the process of creating smart buildings with near zero energy consumption and secures a good thermal and visual environment.

## 3. Dynamic elements for reduction of energy needs

In the following we describe the development of the dynamic façade system that addresses all of the constituents of the energy consumption. For the control of dynamic U-value technologies such as the shutter technology requires in depth analysis of the thermal performance including description of the air leakage. The correct control of the solar shading requires the understanding of the solar shading properties at different incident angles.

### *3.1. Reducing the thermal heat transmission loss*

The glazed part of the façade gives by far the largest contribution to the transmission heat losses through the building envelope. On the other hand, the glazing also contributes significantly to the heating of the building during the periods of the heating season when the sun is shining. The traditional way of reducing the transmission heat loss is by reducing the U-value of the glazing by adding an extra glass layer and an extra low-emission coating. However, extra glass and coating also reduces the passive solar heat gain during the heating season and reduces daylight all year round. This is a strong argument for introducing the dynamic façade in the form of movable insulating shutters as a means to reduce the energy demand for heating.

Shutters have traditionally been used for protection against solar loads. The use of shutters as insulating elements has been discussed from a theoretical view point, e.g. Bülow-Hübe [4] and Faber & Kell [5] while there are few examples of practical investigations of the use in real buildings.

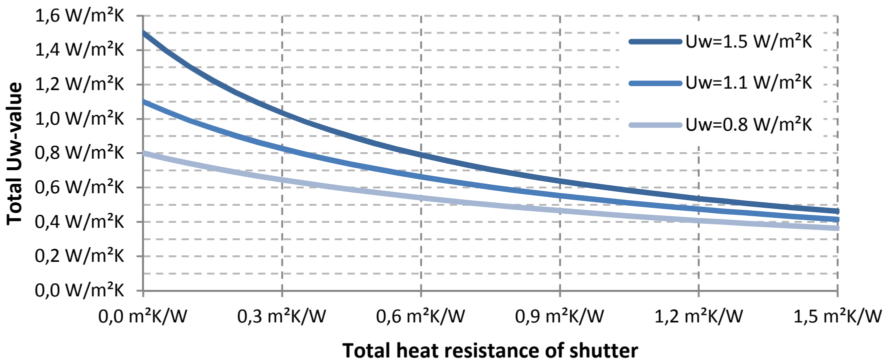


Figure 2. Calculated total U-values for the system of different glazing units with an insulation shutter, as function of the shutter heat resistance.

The development of the insulating Energy Frames elements is based on theoretical analyses as well as tests in laboratory and on real facades. Figure 2 shows the total U-value for the system of glazing and shutter as a function of the shutter's heat resistance and the U-value of the glazing unit. When using a shutter with a heat resistance of 1.0 $m^2K/W$ in front of a 2-layers low-energy glazing unit the total U-value can be reduced to 0.5 $W/m^2K$ as shown on the figure. This gives a potential reduction of the transmission heat loss of about 50 %, and a potential reduction of about 35 % when compared to the traditional choice of a 3-layers low-energy glazing. Table 1 shows the opportunities for adaption of the system properties: U-, g- and LT-values to the any given situation. The reduction of the transmission heat loss is strongly dependent on the *effective* heat resistance of the insulating shutter, especially its ability to reduce the entrainment of air in the cavity between the building skin and the shutter, see section 3.3.

Table 1. Data for typical glazing units and for the *system* of a 2-layer low-energy glazing and the shutter. The shutter has a heat resistance of 1.0 $m^2K/W$ and it has an integrated Venetian blind, giving the system properties shown.

| Glazing / façade system | U-value | g-value | LT |
|---|---|---|---|
| 2-layer low-energy glazing 6-15-4 | 1.1 | 0.61 | 0.79 |
| 3-layer low-energy glazing 6-12-4-10-4 | 0.8 | 0.50 | 0.70 |
| 3-layer solar protective glazing 6-12-4-12-4 | 0.7 | 0.33 | 0.59 |
| System: 2-layer low-E glazing + shutter (dynamic) | 0.5 - 1.1 | 0.05 - 0.61 | 0.02 - 0.79 |

### *3.2. Increasing the utilization of solar gains and daylight and improving view out*

The importance of utilizing solar gain and daylight is often seriously underestimated. Comparing the specifications of typical glazing units with the *system* of a 2-layer low-energy glazing and the shutter (insulating + shading) reveals the potential for increase of the use of solar heat gain and daylight. Table 1 shows that (when the shutter is withdrawn/open) the system allows for 22 % more solar gain and 13 % more daylight than the 3-layer low-E glazing, and 85 % more solar gain respectively 34 % more daylight than the 3-layer solar protective glazing. At the same time the 2-layer glazing gives a better visual environment because of the increased daylight level and a brighter and clearer view to the exterior, especially compared to the poor "solution" with 3-layer solar protective glazing. The high utilization of passive solar heating must be evaluated in conjunction with the possibility of limiting solar load in the summer months. As in most cases, the best solar shading is a movable louver based type, e.g. a Venetian blind that can protect against glare from direct sun and the bright sky while still exploiting daylight and allow a view out. The integrated blinds can reduce the solar load to almost zero (0.05 in Table 1) on sunny summer days and thus almost eliminate the need for mechanical cooling in normal offices and most institutions.

A prototype of an Energy Frames element for natural ventilation has been developed and tested. The results show that in a full-height element the outdoor air can be heated 10 K at an air flow of 10 l/s per meter of the element when the solar irradiance is about 400 $W/m^2$. This will significantly extend the use of natural ventilation.

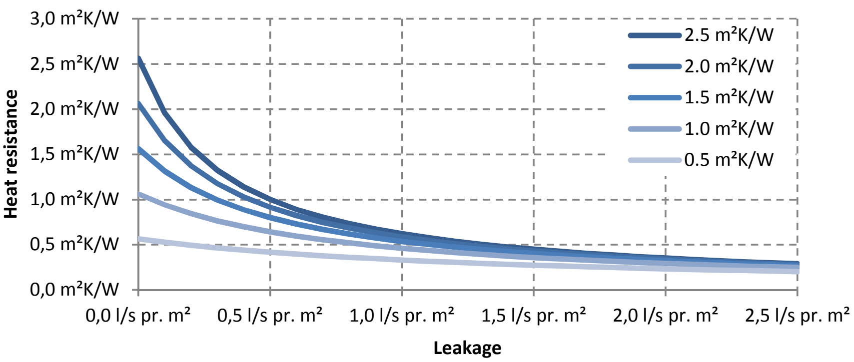

Figure 3. The graph shows the effective heat resistance for different shutter resistances as function of leakage in blower-door test at 50 Pa.

### *3.3. Importance of air tightness of shutter element for reduction of transmission heat loss*

As mentioned, the effective thermal resistance of the dynamic U-value technology is dependent on the materials' thermal conductance and the technologies' ability to minimize the entrainment of air in the cavity between the building skin and the shutter. Figure 3 shows the influence of the air leakage (at a pressure difference over the shutter of 50 Pa) on the effective thermal resistance of the dynamic U-value technology. The figure shows that the air leakage must be significantly lower than 0.5 l/s per m² facade in order to have real benefits of the shutter. Tests have been conducted in the laboratory with different types and different positions of rubber lips as tightening technology. The best results obtained indicate that an air leakage of about 0.15 l/s per m² would be achievable, both in the case of over-pressure and under-pressure. An effective thermal resistance of about 1.0 m²K/W therefore seems to be realistic.

## 4. From the dynamic to the intelligent facade

A prerequisite for the dynamic facade to both reduce transmission losses and increase the use of solar energy and daylight is that the façade adapts to the changing needs. Taken to its ultimate development, the facade should be interactive and respond intelligently and reliably to the changing outdoor conditions and occupants needs. Looking at the many functions of the dynamic facade and the large number of parameters, which at all times should adapt to the current needs, the optimizing task may seem to be very complex. However, for any specific geographical location and climate it is possible to define 12 basic control situations, as shown in Table 2. For the given building and the specific location the shifts between 'seasons' will have to be defined, e.g. from mean daily temperature and typical solar intensity. Also the border between 'sun' and 'overcast' should be defined, e.g. in terms of solar intensity and/or expected hours of sunshine (using weather forecast). The 'optimal' strategies in summer and winter are pretty straight forward, while the strategy in the transition periods may cause some challenges especially in periods when there is a delicate balance between increased use of solar heating and daylight and reduced transmission loss. In any situation the operating system must 'know', whether there are users in the building/space or not. When there are users in the space the control system goes into *comfort mode* and prioritizes the users' needs over the energy efficiency. Some time (minutes) after the users have left the space the system switches to *energy mode* prioritizing energy efficiency. In comfort mode the dynamic façade is adjusted to meet all comfort criteria.

In the comfort mode the users' preferences will often be well correlated with the optimal energy strategy. But there are potential conflicts, for instance at moments when the occupants prefer to have the blinds open and a free view out, while the best energy strategy would be to minimize the solar gain and the need for cooling. It is necessary to accept this kind of trade-offs, since there is increasing evidence that occupants strongly prefer to have some level of personal control of their local indoor environment. This may result in better overall work satisfaction and perhaps better performance and productivity at a very small extra cost for energy.

Table 2. The 12 basic automatic control situations to handle with the dynamic façade. Automatic control is a prerequisite for dynamic façade but with possibility of manual overruling.

| Season | Occupants and control ‘mode’ | Weather |
|---|---|---|
| Summer | Present: Comfort mode | sun |
| | | overcast |
| | Off -hours: Energy mode | sun |
| | | overcast |
| Winter | Present: Comfort mode | sun |
| | | overcast |
| | Off- hours: Energy mode | sun |
| | | overcast |
| Spring/autumn | Present: Comfort mode | sun |
| | | overcast |
| | Off- hours: Energy mode | sun |
| | | overcast |

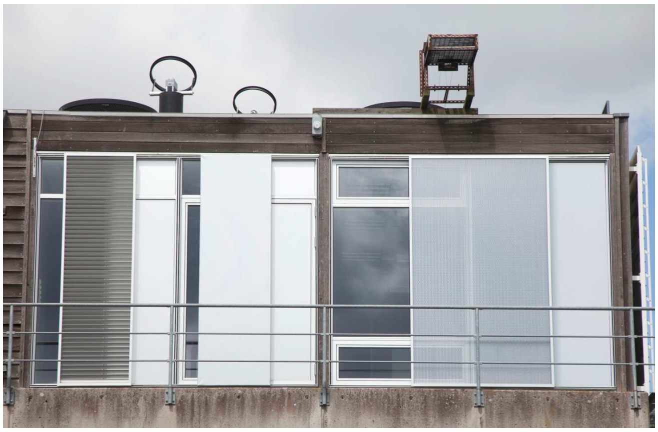

Figure 4. Three prototypes of Energy Frames elements were initially tested in the Daylight Laboratory at the Danish Building Research Institute: Two shading types, one screen and one louver based plus one insulating, transparent element.

## 5. Conclusion: Energy consumption with static facades vs. Energy Frames

While the total energy need with the traditional static façade cannot be lower than app. 50 kWh/m² per year, simulations of a typical office building [6] have shown that it is possible to meet the future Danish Energy requirements, as low as 25 kWh/m² per year, by using dynamic façade components with a smart control system. The simulated energy needs are:

- Reduced transmission heat loss and increased utilization of solar gain cuts the energy for heating to 2 kWh/m² yr
- Increased daylight utilization and improved control cuts the need for electricity to lighting to 8 kWh/m² yr
- Preheating of venting air and increased time of natural ventilation cuts energy need for ventilation to 6 kWh/m² yr
- Effective control of the solar gain almost eliminates the need for mechanical cooling, reducing it to 1 kWh/m² yr
- The energy for miscellaneous - hot water production, pumps, etc. - is assumed to be unchanged at 6 kWh/m² yr.

The control strategy for minimizing the energy consumption for building services focuses on the control of the energy transport across the building skin optimizing the conditions behind the façade dependent on the demand for lighting, optimal temperature conditions and fresh air, whilst minimizing unnecessary heat loss or heat gain. The façade thus interacts with the surrounding environment in relation to the users demand or the demand for building services.

## Acknowledgements

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