Insulating shutters: innovative enhancements for energy saving, comfort, and security

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Abstract

Outside shutters are used extensively in European housing stock to provide shading, privacy, security, and add aesthetic appeal. However most shutters are hand operated and almost none provide good insulation. Yet windows systems, particularly in older housing stock, tend to be quite wasteful. The addition of well insulated and air sealed shutter systems can substantially limit radiant, convective, and conductive losses in both summer and winter, thereby saving energy and increasing comfort.

This paper describes progress on research aimed at developing a family of insulating shutters suitable for retrofit or new building stock in the European community. It discusses costs and energy savings of the shutter systems under varying circumstances of weather conditions and existing fenestration. The shutters under development have the following properties:

- When closed, increase the effective insulating value of a single-glazed window by a factor of nearly 12 (comparing a single pane clear glass window with indoor shade to the same window, air gap, and shutter system);
- Slide open and shut on fixed elements, thereby providing extra strength in wind and snow;
- May be equipped with a variety of facades to accommodate special operational or aesthetic needs;
- Are operated by means of self-contained stepper motors, electronics, and photovoltaic power supplies to facilitate inexpensive installation on new and retrofit buildings;
- Are automated to optimize energy performance year around, while automatically responding to emergencies such as high winds or fire.
- May be manipulated by occupants to over-ride automatic operation.

Introduction

Exterior window shutters are in wide spread use in the European Union as well as many other areas of the world. They are readily available in a range of sizes, shapes, and designs to fit a wide range of window dimensions and to serve a variety of functions. Many shutter designs add aesthetic value to buildings, while and meeting requirements specific installations such as recessed windows or the lack of space due to narrow spacing of windows, thereby requiring folding shutters. Window shutters traditionally serve additional functions, including privacy, security, protection from weather, and shading while allowing ventilation.

Figure 1 shows photos of shutters on buildings in Paris and Nice, and illustrates some of these features–and the lack of others. In addition to these useful features, exterior shutters drawbacks often include low insulating value and high air leakage. Accordingly they provide little thermal advantage, other than blocking direct beam solar radiation as desired in the summer.

Insulating exterior window shutters described here perform an insulating and air sealing function in addition to

Figure 1. Window shutters on buildings in Paris and Nice.

shading, security, and protection from weather. As a result, energy savings and comfort would be enhanced in all weather areas of the EU. Additionally, adoption of this shutter technology would result in the reduction of peak electrical demands required for air conditioning and peak gas supplied for heating.

Finally, when shutters are automated in discrete ways and controlled to optimize energy performance, additional advantages are readily apparent. Automated operation, with manual and emergency override capabilities, meets the occupant's requirements for natural daylight while helping to minimize energy required for heating and cooling the space. Automated operation allows for user-specified desires to be programmed into the control system. Then, within these constraints, energy use minimization algorithms can be continuously applied to determine when individual shutters should be closed and opened. Thus shutters can be configured for maximum performance throughout the day. Manual override is always available when circumstances demand a configuration outside the programmed schedule.

DESIRED DESIGN CRITERIA

External insulating shutters as described in this paper are designed according to criteria that add direct value as well as intangible benefits to the consumer. These include reducing heating and cooling costs, increasing comfort, reducing night time light and noise, increase security and reduce the likelihood of damage or flooding resulting from severe weather. Additionally, to be successful, the shutter design must be easy to assembly, provide for multiple façade options, install quickly, perform reliably for many years, and be profitable at a price that is cost effective for the home owner.

PERFORMANCE

Exterior insulating shutters should improve the performance of any window system no matter whether it is the most modern state of the art technology or the original single pane windows on a two hundred year old home. To determine the thermal and economic benefits of adding exterior insulating shutters to homes, simulations were performed for a residence in seven European cities including both warm and cold climates using the Energy 10 building simulation software tool (Energy 10).

The house modelled is a square, single story, 139.4 m^2 home of standard wood frame construction with a total conduction, UA = 225 W/°C. Heating and cooling equipment were automatically sized by the Energy 10 program for each climate analyzed. Heating system efficiency was specified to be 80 percent and the air conditioner had an 8.9 energy efficiency ratio.

The total window area was 26 m2, divided into 14 equally sized, 1.22 m by 1.52 m windows with 4 each on the north and south walls and 3 each on the east and west walls. The windows used in the simulation were single glazed clear glass with a thermal conductance, U = 5.65 W/m2-°C and a solar heat gain coefficient of 0.86. For the case with the shutters closed a conductance U = 0.44 W/m2-°C was used for the system (window and shutter).

Results of the simulations are shown in Table 1 for the seven cities analyzed. This table shows the total annual building cooling and heating energy required for the reference case (no shutters) and for the case with in which shutters were added to the windows.

PROGRESS OF RESEARCH TO DATE

During the initial phase of exterior insulating shutter development different shutter operating configurations were evaluated, including swinging shutters, with two different operating mechanisms, and sliding shutters. All system designs employed manual crank operation, similar to casement windows. Installation of the crank mechanism required drilling a hole in the wall of the house through which the crank extended (SRC 1982).

While the current shutter design does not provide a complete air seal against infiltration it does provide a cavity of near still air that can when used with older, leaky windows,

Table 1. Cooling and Heating energy use with and without shutters.

City	Reference case – no shutters		With insulating shutters		Energy saved	
	Cool (kWh)	Heat (GJ)	Cool (kWh)	Heat (GJ)	Cool (kWh)	Heat (GJ)
Athens	4 977	24	2 837	15	2 140	9
Berlin	1 143	112	424	85	719	27
Madrid	3 529	46	1 608	31	1 921	15
Paris	1 986	84	410	61	1 576	23
Rome	3 841	34	1 883	22	1 958	12
Strasbourg	1 514	92	690	68	824	24
Zurich	1 058	100	311	74	747	26

significantly reduce infiltration. The extruded aluminium frame is designed to accept a strip of pile weather stripping. When closed this sealing method encloses the entire shutter.

Infiltration tests were conducted to verify the performance improvements of the shutter/window system to the double hung window alone. Testing consisted of measuring air flow through cracks surrounding the window, shutter, and window/shutter system and then normalizing this to the crack length. The window tested was the state of the art available in 1982, many of which are still in use and will be for many years to come. At 25 Pa air pressure differences the shutters reduce infiltration on this particular window by about 65% while at higher pressure differentials, 100 Pa the reduction is more modest but still significant at 38%.

The initial prototype units used 25 mm (1 inch) thick rigid thermax insulation. This shutter design had an insulating value of R 1.27 m2-°C/W and a 3 to 7 times improvement in thermal performance over most windows installed or on the market at that time. Figure 2 shows the original shutter construction with the extruded aluminium edge frames removed.

Early prototype units were up to the challenge and performed well. Their thermal performance was unsurpassed by any commercially available window system of the time, providing value in both summer and winter. While these tests indicate the concept will provide many advantages over the status quo, technological advances have provided the opportunity for further improving on this practical energy saving technology.

CHARACTERISTICS OF THE IMPROVED VERSION

In the two decades between the initial prototype development and the recent resurrection of this concept many and significant advances have been made in the electronic, robotics, and microcontroller industries providing excellent and inexpensive sensors, energy storage devices, and wireless technology. Additionally, the thermal performance of both rigid insulation and weather stripping has improved and it is readily available in a variety of types, thicknesses and at a reasonable price.

Façades

To cost-effectively meet the aesthetic requirements of the shutters, a variety of façade materials have been identified that are inexpensive, easily formed or built up, and provide the practicality of design required. The original prototype used an ultraviolet-resistant plastic called UVEX and was vacuum formed to give the appearance of a louvered shutter. This approach has the significant benefit of low cost moulds, which in turn allow for production of façades, and therefore shutters, in a near infinite range of sizes.

Additional candidate façade materials have been identified and are being evaluated for performance, manufacturability, cost, durability, and aesthetic value. Some of these include UV stabilized ABS plastic, wooden facades, cementous board for additional fire protection, stamped metal, such as aluminium and steel, and Kevlar, either as a façade material or as additional panels within the shutter to provide added security.

Controllability

Control of the exterior insulating shutters is designed to be extremely easy as well as to provide the greatest possible flexibility. The control system is programmable for the general daily operation and easily overridden with a small, hand held remote control similar in size to an automobile handheld keyless entry and alarm activation device. For automatic operation, each shutter in the building is programmed as part of the installation process. Programming provides for user-specified functionality as well as optimizing energy efficiency within the constraints provided by the user. These functions then take place automatically on a daily basis.

Safety is of the utmost importance to all. The onboard control and power supply and no external wiring eliminate "loss of utility power" as a failure mode. In the event of an interior fire all shutters automatically open. In addition to the shutters opening as a result of a signal from an internal

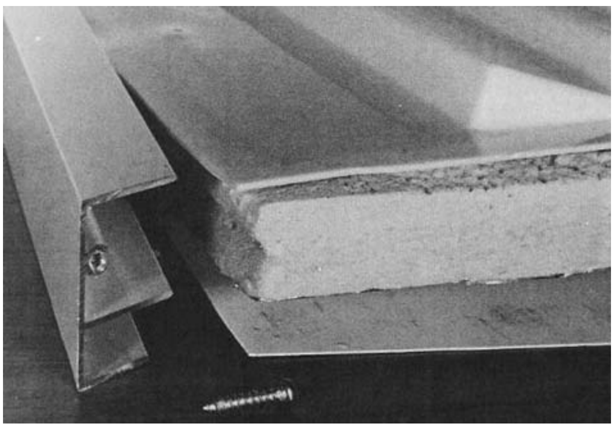

Figure 2. Shutter construction. *The original design used a vacuum formed UVEX façade. 25 mm thick shet of thermax insulation, and a styrene back panel. The lower shutter frame aluminium extrusion is shown to the left.*

Table 2. Energy costs, shutter costs, and simple payback.

	Electricity Euro/kWh	Natural gas Euro/GJ	Cooling cost savings (Euro/kWh)	Heating cost savings (Euro/GJ)	Total annual savings (Euro)	Simple bayback (years)
Athens	0.11	9.54	235	82	317	16
Berlin	0.14	12.62*	101	345	446	12
Madrid	0.11	15.34	211	226	437	12
Paris	0.14	13.00	95	301	396	13
Rome	0.20	17.59*	392	200	592	9
Strasbourg	0.14	13.00	115	309	424	12
Zurich	0.14	14.18	105	368	473	11

Source: Energy prices IEA (except * Eurostat)

fire alarm system, an external fire indicating system can be integrated into the control. In this case the signal sounds an alarm within the residence and closes the shutters. When wind pressure exceeds a predetermined level, as would be the case with a hurricane or tornado, the shutters automatically close, protecting the occupants and their belongings inside the building

Power supply, energy storage, and drive mechanism

The average power required to operate the shutters is just a few watts. Due to this low power draw and the limited number of daily shutter cycles, an optional small 75 cm^2 photovoltaic panel and a 50 farad super capacitor are able to provide the power and energy storage requirements for 2 to 3 days of normal operation. This approach provides a number of benefits including a completely self contained system (except possibly north facing shutters which may be wired to a remote PV panel mounted on adjacent walls), that reduces installation cost since an electrician is not required, does not add electrical requirements to off grid homes, and will operate unattended in the event of a power outage in grid connected homes.

Insulation

The current generation of shutters utilizes 38 mm rigid polyisocyanurate, or equivalent, insulation with an aluminized radiant barrier. Increasing the insulation thickness from 25 mm to 38 mm and utilizing a product with a higher thermal resistance compared to that used in the prototype units will increase the thermal resistance of the shutter to approximately R=2.11 m2-°C/W, a 66% increase with minimal incremental impact on the overall shutter price.

Manufacturability

The shutter system described here is designed to be extremely rugged and easily manufactured at a modest cost. The shutter system consists of two primary subsystems, the mounting system and the shutters themselves. These are standard cross sections of extruded aluminium for all shutters but vary in length depending on the height and width of the window. In production volumes it is expected the assembly process will be completed in less than one hour.

Time required for installing the mounting systems and shutters on the individual facility will depend on a number of factors but is primarily dependent on the number of floors in the structure. Single story homes will be straight forward and it is expected that a crew of two can complete the installation in one working day for an average residence of 12 windows.

Cost and economic figures of merit

As is always the case, performance and cost vary and depend on a number of parameters. While the performance of an individual shutter can be determined, its performance, and economic benefit, depends on the existing window system, fuel costs for heating and air conditioning, and climactic conditions. As expected, when existing windows are single pane and non-coated, fuel costs are high, and the climate is harsh (in either summer or winter) the economic benefits are greatest.

It is expected that in modest production volumes, on the order of several thousand units per year, and where labour costs are appropriate for the skill set requires the cost of the shutters will be on the order of 200 Euro to 270 Euro per m^2 installed with the smaller cost per unit area being for larger shutter units. Assuming a size range of windows to be on the order of 0.5 to 1.5 m^2 the total installed cost is expected to be on the order of 150 Euro to 300 Euro per shutter system. These estimates are based on the sum of cost estimates for materials, manufacturing labour, installation labour, overhead, and profit.

It is expected that on new construction projects the purchase price of the shutters would be included in the home mortgage. This would likely be the case for many retrofit projects in the form of a second mortgage or home equity loan.

Estimated energy savings for the cities considered were presented in Table 1. Associated total cooling and heating energy costs are presented in Table 2 along with savings and budgetary first cost for installing the shutters in the simulated home. Since the shutters used in this particular simulation were large, the lower end of the cost ranges is used to determine the total installed cost of the shutters for this building. At 200 Euro/m^2 and with 26 m^2 of shutters, the installed cost is estimated to be 5 200 Euro.

While the simple payback periods indicated in Table 2 may be longer than typically acceptable, when compared to the possible alternative of replacing windows, the incremental cost would be minimal or even be negative. Further, the insulating shutter option will provide substantial energy savings and much simpler installation, as well as improved security, night time noise and light reduction, and added protection against severe weather.

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