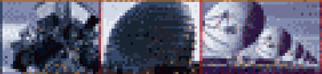
SMART INNOVATION, SYSTEMS AND TECHNOLOGIES 22

Anne Håkansson
Mattias Höjer
Robert J. Howlett
Lakhmi C. Jain
Editors



Sustainability in Energy and Buildings

Proceedings of the 4th International
Conference on Sustainability in
Energy and Buildings (SEB'12)

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Professor Guðni A. Jóhannesson	Icelandic National Energy Authority, Iceland,
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Keynote Speakers

We are very pleased to have acquired the services of an excellent selection of keynote speakers for SEB'12. These speakers gave a view about technological and scientific activities, relating to sustainability in energy and buildings, taking place in various areas of the world.

Professor Göran Finnveden

KTH Royal Institute of Technology, Sweden

Sustainability Challenges for the Building Sector

Abstract:

The building and real estate management sector is responsible for a significant part of the environmental impacts of our society. The sector's contribution to the threat of climate change for production of heat and electricity for the buildings are of special importance. It is important to consider the full life-cycle of buildings and also consider

production and transportation of building materials, construction and waste management. In Sweden, emissions of gases contributing to climate change from heating of buildings have decreased during the last decades as results of strong policy instruments. One the other hand emissions from other parts of the life-cycle of buildings have increased, illustrating the need to have a wide systems perspective in order to avoid sub-optimizations. It is also important to consider other environmental threats such as the use of hazardous chemicals, air quality, generation of waste and impacts on ecosystems from production of building materials as well as on building sites.

The building sector has a large potential to reduce its environmental footprint. Many of the most cost-efficient possibilities for mitigation of climate change are related to the building sector. Governmental policies are important for changes to be made. Voluntary instruments such as building rating tools may have an additional role. The ICT-sector may have one of its largest potentials in contributing to a more sustainable society in the building sector. Because of the long life-time of buildings, we are now constructing the future environmental impacts. When looking for cost-efficient solutions, we must therefore also consider the future cost-efficiency. In the presentation also social aspects of sustainability will be discussed including possibilities for the building sector to contribute to a better health and reduced health inequalities.

Biography:

Göran Finnveden is Professor in Environmental Strategic Analysis and Vice-President for sustainable development at KTH Royal Institute of Technology, Stockholm, Sweden. He is a M.Sc. in Chemical Engineering 1989, PhD in Natural Resources Management, Associate Professor in Industrial Ecology 2003 and full Professor 2007. His research has focused on environmental systems analysis tools such as Life Cycle Assessment, Strategic Environmental Assessment and Input-Output Analysis. It has included both methodological development and case studies. Application areas include buildings, energy systems, information and communication technologies, infrastructure and waste management. He has also worked with environmental policy in areas such as environmental policy integration, integrated product policy and waste policy. He is a currently a member of the Scientific Advisory Council to the Swedish Minister of the Environment, an expert in the governmental commission on waste management and a member of the board of directors of the Swedish Waste Nuclear Fund. According to Scopus he has published more than 60 scientific papers and is cited nearly 2000 times.

Professor Per Heiselberg

Aalborg University, Denmark

Buildings – both part of the problem and the solution!

Abstract:

Energy use for room heating, cooling and ventilation accounts for more than one-third of the total, primary energy demand in the industrialized countries, and is in this way a major polluter of the environment. At the same time the building sector is identified as providing the largest potential for CO2 reduction in the future and many countries across the world have set very ambitious targets for energy efficiency improvements in new and existing buildings. For example at European level the short term goal has recently been expressed in the recast of the EU Building Performance Directive as "near zero energy buildings" by 2020.

To successfully achieve such a target it is necessary to identify and develop innovative integrated building and energy technologies, which facilitates considerable energy savings and the implementation and integration of renewable energy devices within the built environment. The rapid development in materials science, information and sensor technology offers at the same time considerable opportunities for development of new intelligent building components and systems with multiple functions.

Such a development will impose major challenges on the building industry as building design will completely change from design of individual components and systems to integrated design of systems and concepts involving design teams of both architects, engineers and other experts. Future system and concepts solutions will require that building components must be able fulfill multiple performance criteria and often contradictory requirements from aesthetics, durability, energy use, health and comfort. A key example of this is building facades that instead of the existing static performance characteristics must develop into dynamic solutions with the ability to dynamically adjust physical properties and energetic performance in response to fluctuations in the outdoor environment and changing needs of the occupants in order to fulfill the future targets for energy use and comfort. Buildings will also be both consumers and producers of energy, which creates a number of new challenges for building design like identification of the optimum balance between energy savings and renewable energy production. The interaction between the energy "prosuming" building and the energy supply grid will also be an important issue to solve.

The lecture will address and illustrate these future challenges for the building sector and give directions for solutions.

Biography:

Per Heiselberg is Professor at the Department of Civil Engineering at Aalborg University, Denmark. He holds a M.Sc. and a Ph.D. in Indoor Environmental Engineering. His research and teaching subjects are within architectural engineering and are focused on the following topics:

- Energy-efficient building design (Net zero energy buildings, design of low energy buildings - integration of architectural and technical issues, modelling of double skin facades, night cooling of buildings and utilization of thermal mass, multifunctional facades, daylight in buildings, passive energy technologies for buildings, modeling of building energy use and indoor environment)

- Ventilation and air flow in buildings (Modelling and measurements of air and contaminants flows (both gas- and particles) in buildings, ventilation effectiveness, efficient ventilation of large enclosures, numerical simulation (computational fluid dynamics) of air and contaminant flows as well as modeling of natural and hybrid ventilation)

Per Heiselberg has published about 300 articles and papers on these subjects.
Currently, Per Heiselberg is leading the national strategic research centre on Net Zero Energy Buildings in Denmark (www.zeb.aau.dk). The centre has a multidisciplinary research approach and a close cooperation with leading Danish companies. He has been involved in many EU and IEA research projects in the past 20 years. He was the operating agent of IEA-ECBCS Annex 35 (1997-2002) and IEA-ECBCS Annex 44 (2005-2009), (www.ecbcs.org). Presently he is involved in ECBCS Annexes 52, 53 and 59.

Professor Guðni A. Jóhannesson

Icelandic National Energy Authority, Iceland

Meeting the challenges of climatic change - the hard way or the clever way

Abstract:

We may not agree on how the possible CO2 driven scenarios of climate change in the future may look like but we all can agree that the anthropogenic increase in CO2 levels in the world atmosphere exposes humanity to higher risks of changes in the environment than we want to face in our, our children's or their children's lifetime.
It is evident that we are now facing a global challenge that we are more often dealing with by local solutions. Our guiding rule is that by saving energy we are also mitigating greenhouse gas emission. Also if we are using renewable energy and substituting fossil fuels we are also moving in the right direction. There are however important system aspects that we should be considering.
The first one if we are using the right quality of energy for the right purpose. A common example is when high quality energy such as electricity or gas is used directly to provide domestic hot water or heat houses instead of using heat pumps or cogeneration processes to get the highest possible ratio between the used energy and the primary energy input.
The second one is if we are obstructing necessary structural changes that could lead to a more effective energy system globally. We have big reserves of cost effective renewable energy sources, hydropower and geothermal energy around the world that are far from the markets and would therefore need relocation structural changes in our industrial production system to be utilized.
The third aspect is if we are using our investments in energy conversion and energy savings in the best way to meet our climatic goals or if we are directed by other hidden agendas to such a degree that a large part of our economical input is wasted.
It is evident that the national and local strategies for energy savings are closely linked to other strategic areas such as industrial development, household economy, mobility.

Also a necessary precondition for investment is that the nations maintain their economic strength and their ability to develop their renewable resources and to invest in new more efficient processes.

The key to success in mitigating the climatic change is therefor to create a holistic strategy that beside the development of technical solutions for energy efficiency and utilization of renewable energy also considers the local and global system aspects. With present technologies for energy efficient solutions, proper energy quality management r and with utilization of cost effective renewable energy sources we have all possibilities to reduce energy related the global CO2 emissions to acceptable levels.

Biography:

Professor Guðni A. Jóhannesson is born in Reykjavik 1951. He finished his MSc in Engineering physics in 1976, his PhD thesis on thermal models for buildings in 1981 and was appointed as an associate professor at Lund University in 1982. He was awarded the title of doctor honoris causae from the University of Debrecen in 2008 and the Swedish Concrete Award in 2011. From 1975 he worked as a research assistant at Lund University, from 1982 as a consultant in research and building physics in Reykjavik and from 1990 as a professor in Building Technology at KTH in Stockholm and from 2008 an affiliated professor at KTH. His research has mainly concerned the thermodynamical studies of buildings, innovative building systems and energy conservation in the built environment. Since the beginning of 2008 he is the Director General of the Icelandic National Energy Authority which is responsible for public administration of energy research, energy utilization and regulation. He was a member of the The Hydropower Sustainability Assessment Forum processing the Hydropower Sustainability Assessment Protocol adopted by IHA in November 2010 and presently the chair of IPGT the International Partnership for Geothermal Technologies.

Professor Lynne A. Slivovsky

California Polytechnic State University, USA

The Questions That Keep Me Up At Night

Abstract:

This keynote will provide an opportunity for reflection on the work we do. We're here talking about energy and sustainability but we're also talking about a different way of living. We, as a technical field, a society, a world, are on a path of profound technological development. What does it mean to educate someone to contribute to this world? To have a technical education? What does it mean to live in this world? And is it possible that we as designers, innovators, engineers, and scientists can consider these questions in our day-to-day work?

Biography:

Lynne A. Slivovsky (Ph.D., Purdue University, 2001) is Associate Professor of Electrical and Computer Engineering at California Polytechnic State University, San Luis Obispo, California, USA. In 2003 she received the Frontiers In Education New Faculty Fellow Award. Her work in service-learning led to her selection in 2007 as a California Campus Compact-Carnegie Foundation for the Advancement of Teaching Faculty Fellow for Service-Learning for Political Engagement. In 2010 she received the Cal Poly President's Community Service Award for Significant Faculty Contribution. She currently oversees two multidisciplinary service-learning programs: the Access by Design Project that has capstone students designing recreational devices for people with disabilities and the Organic Twittering Project that merges social media with sustainability. Her work examines design learning in the context of engagement and the interdependence between technology and society.
Panel: Sustainability: Current and Future with focus on Energy, Buildings and ICT

Panel:

Sofia Ahlroth, Working Party on Integrating Environmental and Economic Policies (WPIEEP), Swedish EPA
Magnus Enell, Senior Advisor Sustainability at Vattenfall AB, Sweden
Göran Finnveden, Professor, KTH Royal Institute of Technology, Sweden
Danielle Freilich, Environmental expert at The Swedish Construction Federation (BI), Sweden
Catherine.Karagianni, Manager for Environmental and Sustainable Development at Teliasonera, Sweden
Örjan Lönngren, Climate and energy expert, Environment and Health Department, City of Stockholm, Sweden
Per Sahlin, Simulation entrepreneur, Owner of EQUA Simulation AB, Sweden
Mark Smith, Professor, KTH Royal Institute of Technology, Sweden
Örjan Svane, Professor, KTH Royal Institute of Technology, Sweden
Olle Zetterberg, CEO, Stockholm Business Region, Stockholm, Sweden

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Chapter 15

Raising High Energy Performance Glass Block from Waste Glasses with Cavity and Interlayer

Floriberta Binarti[1], Agustinus D. Istiadji[1], Prasasto Satwiko[1], and Priyo T. Iswanto[2]

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Abstract. The main glazing energy performance measure in warm humid climates is light-to-solar-gain ratio (LSG), which denotes the ratio of the visible light transmittance (VT) and its solar heat gain coefficient (SHGC). In laminated glazing the LSG depends on the design of the cavity and (inter)layers. This study explored the contribution of cavity and interlayer in raising high energy performance glass block from laminated waste glasses. Analytical method and computational simulations using comparative method and heat balance model were employed to obtain glass block model with the most optimum combination of the VT, the SHGC and its thermal transmittance (U). The effect of cavity on increasing the VT was showed by simulation and laboratory test results. Based on SHGC laboratory tests, the presence of interlayer declined 69-89% of the simulated SHGC. Laminated glass block with certain number of closed cavity and interlayer can raise 4.35 of the LSG.

Keywords: cavity, glass block, interlayer, light-to-solar-gain ratio, solar heat gain coefficient, visible light transmittance.

1 Introduction

Building energy consumption can be reduced by adopting high energy performance glazing. In warm humid climates high energy performance glazing should have high ratio of the visible light transmittance (VT) and its solar heat gain coefficient (SHGC), which is called as Light-to-Solar-Gain Ratio (LSG). Thermal transmittance (U) is important for air conditioned buildings. Low-U building envelope can reduce the conductive heat transfer rate, which further cuts down the building cooling load. According to Energy Conservation Code 2006 vertical fenestration in warm humid climates is recommended to have 0.25 for the maximum SHGC and 3.177 W/m^2.K for the maximum U with 0.27 of the minimum VT for small fenestration area [1].

Lamination is the selected method to produce new glass block from waste glasses. This low-technology method potentially creates low U and low SHGC material. The SHGC, the VT, the U and the mechanical strength of the layers bonding depend on the layer number, the interlayer and lamination technique. Chen and Meng [2] studied

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the contribution of interlayer by examining the effect of polyvinyl butyral (PVB) laminated glass application on the building cooling load. The simulation results showed that application of 7 mm PVB laminated glass created lowest cooling load compared to the application 12 mm clear glass and 6 mm low-e coated glass.

Cavity was introduced in glass block as thermal resistance. Heat transfer across the cavity depends on the cavity number, dimension, the optical and the thermal properties of the material [3-6]. Cavity avoids significant reduction of the VT due to the transparency for visible light. Material with higher refractive index (RI) is less transparent. Air has 1 for the RI, whereas ordinary clear glass has 1.52.

This study explored the contribution of cavity and interlayer in raising high energy performance by obtaining and testing optimum combination of the layer number, the cavity type, number, width and position. Analytical and computational simulation approaches were used to design glass blocks with proper cavities. Contribution of the interlayer would be examined in laboratory tests.

2 Methods

This study employed several methods that will be explained chronologically. The first step is interlayer selection. Some criteria in selecting interlayer are transparency, emissivity, thermal conductivity, compressive and tensile strength, durability, curing time and price. Clear epoxy resin was selected as the interlayer material. Epoxy resin can form extremely strong durable bonds with glass (50 MPa). Generally epoxy resin has 0.02–0.1 W/m.K for the thermal conductivity and 0.8 for the emissivity. The maximum RI is 1.57.

Cavity inside glass block can be designed as open cavity and closed cavity. In this study cavity type was examined as 1 m^2 vertical fenestration in a 3 m x 3 m x 3 m adiabatic building system using a Computational Fluid Dynamic (CFD) – ACE software package. The accuracy of simulation results of CFD - ACE has been remarkable. Validation conducted by Satwiko et al. [7] described that the air flow analysis are close to the field measurements with deviation from 0.003 until 0.027 for three dimensions with standard k-ε turbulent model. In CFD - ACE geometry and mesh were created in CFD-GEOM. Models were constructed from 285,345 unstructured cell number. Simulations were conducted with steady state laminar model with low air velocity (0.2 m/s). This condition was reached after 200 iterations and 0.0001 for the convergence. Heat flux was set to 540 W/m^2 (at the peak local condition). The exterior surface temperature was set to 50 ^{0}C, whereas the interior surface temperature was set to 26.85 ^{0}C, which represents the lowest average temperature to describe significant effect of the convective heat transfer across each model.

The next step is development of glass block models with selected cavity type. Formula (1) was employed to estimate the U of each model.

$$U=1/[(1/f_0)+(b_1/k_1)+(b_2/k_2)+(b_1/k_1)+R+(b_1/k_1)+(b_2/k_2)+(b_1/k_1)+(1/f_i)] \quad (1)$$

The accuracy of the formula depends on the determination of the external surface conductance in W/m^2.K (f_0), the internal surface conductance in W/m^2.K (f_i), the thermal resistance of cavity in $m^2.K/W$ (R), the glass conductivity in W/m.K (k_1) and the interlayer conductivity in W/m.K (k_2). b denotes the layer thickness in m'. Variation in R depends on the cavity width. Only interlayers among the layers were calculated.

The effects of heat transfer through each model on the airflow rate inside the cavity, the external and the internal surface temperature were simulated by CFD individually. To lighten the central processing unit (CPU) burden, interlayer in each model was neglected. This is also valid for other simulations.

The VT of glass block models was estimated using comparative method of illumination levels simulated by Radiance (plug in Ecotect). Accuracy of the simulation results rely on the models, ray tracing method [8, 9], and simulation setting. Models were constructed to simulate field measurement of the VT with reference to the simulation procedures developed by Laouadi and Arsenault [10]. Each glass block in the VT simulation was installed as a top lighting of a black box with zero reflectance (Fig. 1).

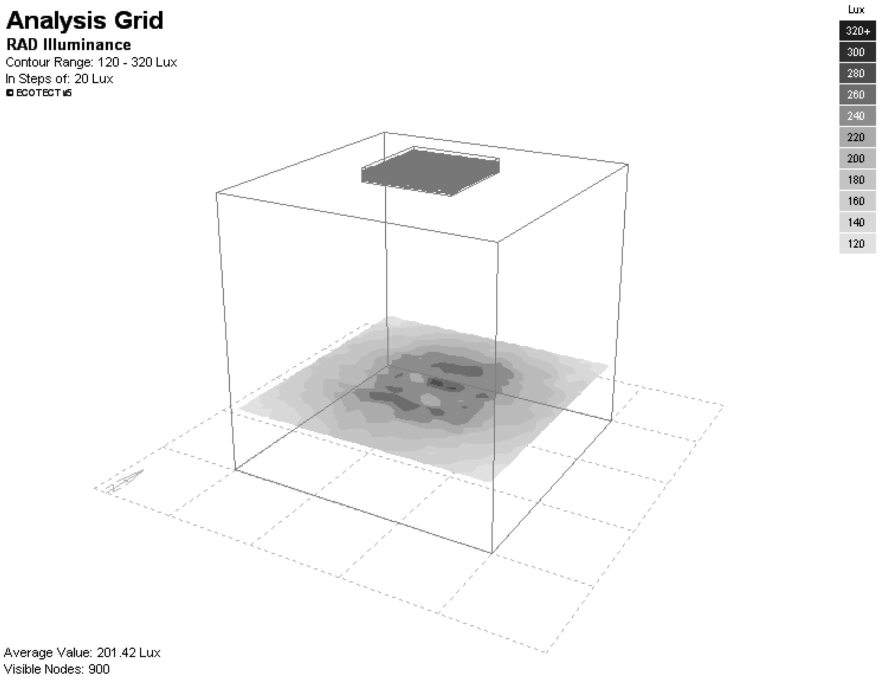

Fig. 1. Simulation model in a black box [11]

The VT of a glass block was obtained from the ratio of the illumination levels transmitted through each glass block to the illumination level captured by a light sensor in the center of black box without glass block. Sky illuminance set up for all simulations is 9897 lux. In this condition (normal incidence angle) the VT is maximum. Validation was conducted using VT field measurement results of single and multiple-glasses with and without cavities. The correction factor is 12% higher than simulation results, which is obtained from the deviation value between the simulation results and the field measurement results.

The SHGC values were obtained by comparing the simulated direct solar gains (in W) of each glass block model ($Q_{g\text{-glassblock}}$) to the one of 3 mm standard glass ($Q_{g\text{-3mm}}$), which were calculated by Ecotect (2).

$$SHGC_{glassblock} = (Q_{g-glassblock} / Q_{g-3mm}) * 0.87 \tag{2}$$

In Ecotect solar heat gain is calculated by Losses and Gains. This facility can analyze heat transfer with admittance method, which works based on cyclic variation concept and is valid under steady state condition. The simulation models were constructed as horizontal fenestration on a roof plane of a zero U and painted black zone. Since the simulation date was set on the hottest day, the results describe the maximum SHGC.

Simulation of heat balance analyzes the quantity of the conductive heat gain (Q_c) and Q_g transferred through each glass block model and the internal heat gain produced by lamp to subtitute the lack of daylighting levels (Q_{lamp}). Models were built as 1 m^2 fenestration on 3 m x 3 m x 3m adiabatic room. The internal heat gain was the heat released by a lamp (Q_{lamp}), which was supplemented to reach the same illuminance level as the illuminance level created by 3 mm standard glass application. One wattage fluorescent lamp power was assummed to produce 11 lux of illumination level and the 20% of the energy was released as heat. The total heat gain was compared to that of the 3 mm glass. In an adiabatic and air-tight room the indirect solar gains, the inter-zonal gains, and the ventilation and infiltration gains are zero.

Q_c refers to conductive heat gains (in W) through a surface area in m^2 (A) due to the air temperature differential (in K) between inside (T_i in ^0C) and outside (T_0 in ^0C) the space and the thermal transmittance (U) of the surface (3).

$$Q_c = U * (T_0 - T_i) * A \tag{3}$$

Whereas, Q_g is the solar radiation (in W) transmitted through a transparent/translucent surface. It depends on the SHGC of the transparent/translucent surface, the total incident solar radiation on the transparent/translucent surface (E in W/m^2) and the glazing area in m^2 (4).

$$Q_g = SHGC * E * A \tag{4}$$

The last step is VT and SHGC laboratory tests to obtain the real LSG. Measurements of the VT referred to the experimental method developed by Wasley and Utzinger [12] with average relative error less than 5% compared to the manufacturer's data. Artificial lighting (Spotone PAR 80 W) replaced the sun to provide weather-independent measurement with less shading and reflection effects from the surrounding environment. Luxmeter Lutron LX-101 with 5% of accuracy deviation was used to measure the illuminance level (Fig. 2). The laboratory VT was obtained from

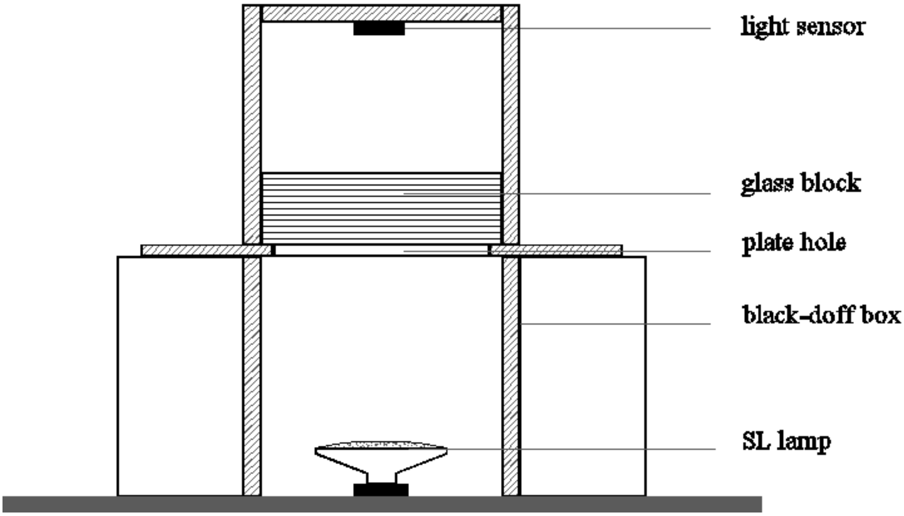

Fig. 2. Schematic apparatus of VT laboratory test

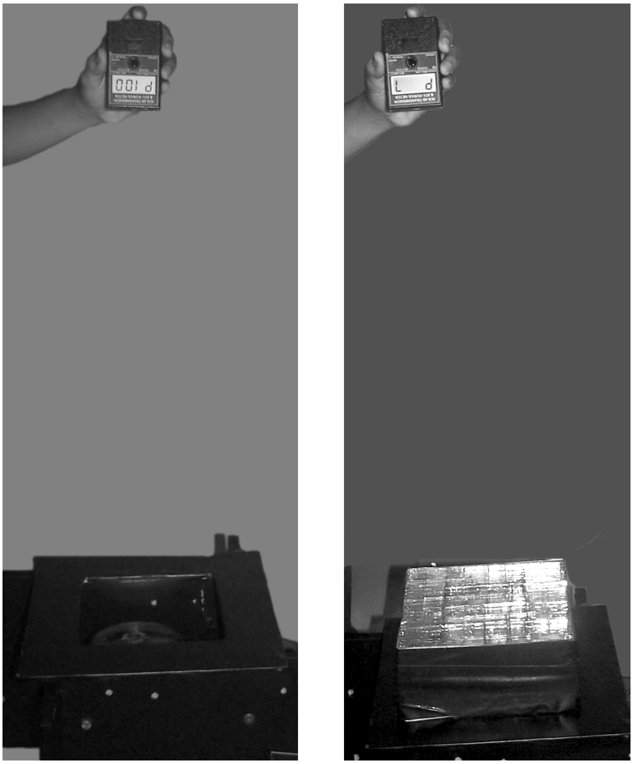

Fig. 3. SHGC measurement using Power meter SP2065: defining the apparatus position (left) and measurement of model l18_l3x2_r2_30 (right)

the ratio of the glass block illuminance level to the illuminance level when no glass was installed. Validation was conducted by comparing the VT measurement of 5 mm clear glass to the standard VT of 5 mm clear glass.

SHGC measurements used digital Solar Transmission and Power Meter model SP2065, which has been factory calibrated to a National Institute of Standards and Technology (NIST) traceable thermopile and requires no field adjustment. An infra red heat lamp (PAR38 150 W) was used as heat radiation source. Self-calibration was done by pressing the power mode. When the display was read P100, the power meter is ready to measure the SHGC of the specimen (Fig. 3). The accuracy of self calibration, therefore, depends on the performance of control microprocessor and the apparatus position consistency. Comparative result of the laboratory SHGC of 5 mm clear glass to the standard value was used to validate the results.

3 Results and Discussions

When glass block models installed as vertical fenestration of 9 m^3 building, lowest indoor temperature was achieved by model with closed cavity (Fig. 4). Closed cavity inside glass block truly functions as thermal insulator. Twelve models with closed cavity, then, were developed with various thickness, cavity width, cavity number, which were selected based on the mechanical strength, the effectiveness of the cavity width and production cost. Table 1 shows that all models have lower U compared to the standard U established by the Conservation Energy Code 2006. Models with more than 30 mm in width cavity have relative high SHGC. None raised 1 for the LSG. Only 4 models with ≥ 10 cm thickness reached low indoor surface temperature (27 ^{0}C).

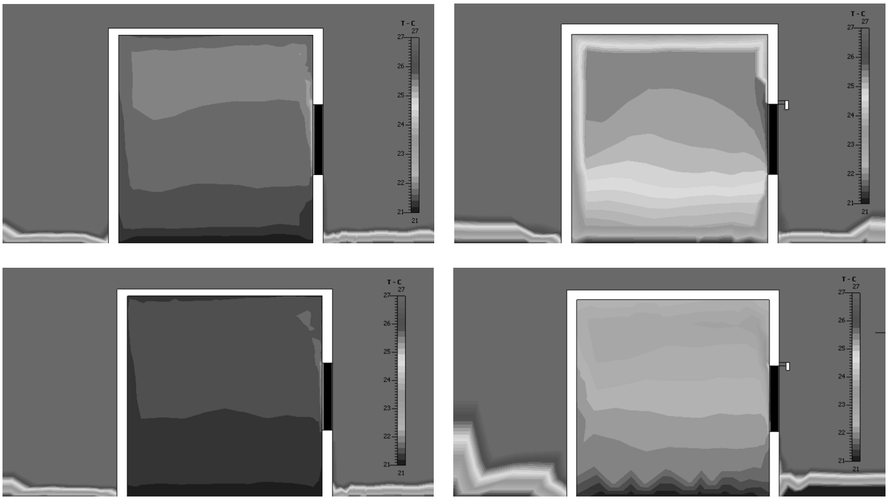

Fig. 4. Temperature profile of application of glass block without cavity (top-left), with open cavity (top-right), with closed cavity (bottom-left), and with open cavity in cooler environment (bottom-right) [11]

Table 1. Energy Performance of Glass Block Models Based on Analytical and Simulation Approach

Model codes[a]	U (W/m^{2}K)	T_{s0}[b] (^{0}C)	T_{si}[c] (^{0}C)	VT	SHGC	LSG
l10_l2x2_r1_30	2.60	77.5	31.5	0.52	0.65	0.80
l11_l2x3_r1_25	2.54	65.5	30	0.41	0.65	0.63
l12_l2x2_r1_40	3.24	78	30	0.52	0.74	0.70
l13_l2x3_r1_35	3.17	67	29	0.40	0.73	0.55
l14_l4x2_r3_10	2.55	75	28	0.40	0.71	0.56
l14_l3x2_r2_20	2.56	77.5	28	0.40	0.72	0.56
l15_l3x3_r2_15	2.50	67	28	0.28	0.70	0.40
l15_l2x3_r1_45	3.06	67	28	0.40	0.71	0.56
l18_l3x2_r2_30	2.60	77	27	0.31	0.57	0.54
l19_l3x3_r2_25	2.54	67	27	0.27	0.59	0.54
l20_l4x2_r3_20	2.30	78	27	0.31	0.67	0.46
l21_l4x3_r3_15	2.28	65	27	0.19	0.66	0.29

[a] Models are coded using lA_lBxC_rD_E formula, which means that A is the total layer number, B is the glass layer number per group, C is the group number, D is the cavity number, and E is the thickness of each cavity in mm.

[b] T_{s0} = outdoor surface temperature

[c] T_{si} = indoor surface temperature

Model l10_l2x2_r1_30 was selected to develop, since it has highest LSG, whereas model l18_l3x2_r2_30 was selected due to its combination of the lowest SHGC and the medium VT (Fig. 5).

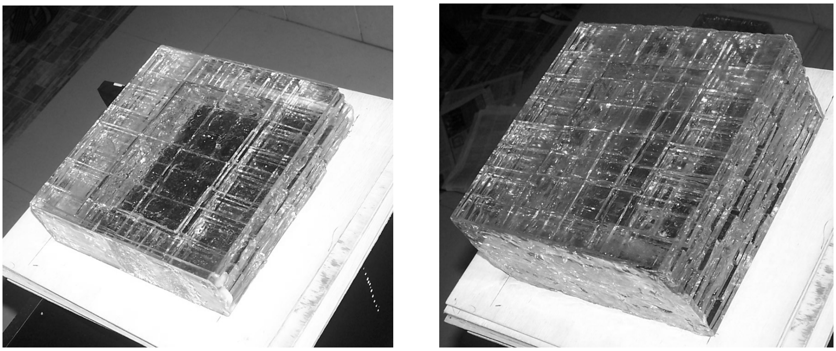

Fig. 5. Prototype of model l10_l2x2_r1_30 (left) and model l18_l3x2_r2_30 (right)

Application of best models, i.e. l10_l2x2_r1_30 and l18_l3x2_r2_30 with closed cavity, in 9 m^3 building model produced 60% to 80% lower heat gain compared to the application of 3 mm clear glass. Table 2 presents the simulation results of the maximum and the minimum heat gains of the best models compared to 3 mm clear glass. Glass block with lower SHGC is more efficient than the one with higher VT.

The SHGC and the VT of each prototype were measured 3-5 times. Table 3 shows that laboratory tests of two prototypes resulted in much lower SHGC compared to the

Table 2. Heat Balance of Best Models

Models	Q_c (W)	Q_g (W)	Q_c+ Q_g (W)	Q_{lamp} (W)	Q_{total} (W)	Efficiency (%)
Oriented to East						
110_l2x2_r1_30	142	328	470	5.8	476	60%
118_l3x2_r2_30	142	151	293	6.2	299	80%
3 mm clear glass	322	1007	1329	0.0	1329	0%
Oriented to South						
110_l2x2_r1_30	142	106	248	5.8	254	60%
118_l3x2_r2_30	142	49	191	6.2	197	70%
3 mm clear glass	322	327	649	0.0	649	0%

simulation results. Low standard deviation in laboratory SHGC, i.e. 1.2%, proved that the results are valid and reliable. Small reductions occurred in the VT with acceptable standard deviation (3.3-4.3%). The LSG of real glass blocks increases due to the lower laboratory SHGC than the simulated SHGC. The real glass blocks consist of interlayer, which contributes more significant in decreasing the SHGC than in decreasing the VT.

A big difference between the percentage difference of simulated SHGC and laboratory SHGC shows that adding glazing interlayer reduced the SHGC more than adding glazing layer. The lower emissivity of the interlayer (0.8) compared to the clear glass emissivity (0.9-0.95) made the glass block emit less heat to the interior. The less transparent (slight higher RI) interlayer compared to the clear glass might create small (percentage) difference of simulated VT and laboratory VT.

Table 3. Laboratory Test Results of the VT and the SHGC

Properties	110_l2x2_r1_30	118_l3x2_r2_30	Percentage Difference
Laboratory VT	0.47	0.30	36%
Simulated VT	0.52	0.31	40%
Laboratory SHGC	0.18	0.06	67%
Simulated SHGC	0.65	0.57	12%
Laboratory LSG	2.50	4.35	(-) 74%
Simulated LSG	0.80	0.54	32%

The wide discrepancy values of the SHGC were probably caused by the accuracy of the simulation program. In simulated SHGC Ecotect did not calculate the absorption and the back transmission of solar radiation occurring among the glazing layers. Whereas, Radiance proved its accuracy in calculating inter-reflections among glass layers described in the simulated VT.

4 Conclusions

Closed cavity with medium width admits optimum visible light and low solar radiation transmitted across the glass block. Cavity width should be no more than 30 mm to avoid high SHGC. Glass block's thickness is another factor determining the SHGC and the indoor surface temperature. The presence of interlayer (epoxy resin) in laminated glass block reduces the SHGC significantly with small reduction in the VT.

Contribution of interlayer in reduction of the SHGC depends on the emissivity. Certain combination of closed cavity and interlayer number can help the glass block to raise high energy performance, i.e. LSG. New interlayer with lower emissivity and lower refractive index can effectively create a higher energy performance laminated glass block.

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