University of West Hungary
Simonyi Károly Faculty of Engineering, Wood Sciences and Applied Arts
Sopron

Doctoral (PhD) thesis

Evaluation of thermophysical properties of windows and improvement of glazing performance

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1. INTRODUCTION

It is not possible to get independce from the economic environment through building of houses or flats. The past few decades made significant changes compare to the last few century. The importance of economic issues has been getting more and more emphasis because 45% of the world energy consumption is coming from the house operations [Paul 1984, Zöld 1999].

Energetic directives and regulations, which are intended to improve the energy performance and economics of buildings, directly affect the window structures that constitute an integral part of the facade of the buildings. Making a comprehensive literature survey it become known that the transmission heat loss can be many times higher than the inefficient filtration loss through newly built in window structures [Emery és Kippenhan 2006]. Because of that many research aims to reduce the heat transfer loss of windows.

Since even the state of art/most modern/ most advanced/ windows are unable to approach the *U*-value of the walls in a building, the development of this area and to find solutions in reducing the heat loss is still demanded. Configure and ensure the proper downer, comfort, fresh air and visual experience windows are basic necessity and a house can not be visualized without windows.

2. PROBLEM STATEMENT

There are several works and studies regarding to the overall thermophysical performance of windows and glazing structures, however the need of new directions and development possibilities are raised recently. The main goal of my research was to clarify and determine the maximal heat efficiency level that can be reached with the currently used window structures, solutions and materials. Moreover the objective of the thesis was also to offer an effective solution to further improve the thermal insulation of windows.

The detailed aims of the study were:

1. Evaluate the characteristic heat performance and power for the present, modern window structures and influencing factors of materials and structures.
2. Evaluate the interaction of available and typical window and receptive wall structures regarding to the view of heat transfer.
3. Determine a method for the built-in window in-situ heat transfer measurements.
4. Searching new directions in order to improve the glazing insulation take in to consideration new optical requirements.

Economic calculations were not aim of the thesis, but improvement of the overall heat performance of well insulated, recent windows are, using available engineering and technological considerations.

3. MATERIALS AND METHODS

Finite element method (FEM) was used to evaluate the overall heat performance of three different, widespread available window structure in Hungary: two wooden frame and one wood-alumina frame windows. FEM method was also used to evaluate the complex interaction of windows in different wall structures because the built-in technique influences the efficacy of the whole building.

Filed studies were carrying out with TESTO-435 multifunctional meter in real environmental circumstances in order to avoid laboratory standard surroundings. With that measuring protocol it has been indicated that the heat insulation performance of windows can not be treated as long lasting. On the measured values, several types of mathematical transformations and operations has been performed in order to characterize the real heat transport phenomena.

To improve the optical and thermal energy performance of window glass layer-by-layer technique was applied. To build up 9 different ultrathin multilayers onto the glass substrate with the self-assembly technique three types of semiconductors (TiO_2, ZnO and SiO_2) were used. The quality of the layers was evaluated by FT-IR spectrophotometry and contact angle measurement. According to the measurements the nanostructured coatings offered reduced heat transfer properties. In order to introduce the glass surfaces self-cleaning mechanism, methyl-orange indicator was selected and tested as can be found in the literature.

Drude-Lorentz type model was applied on modelling the specific heat transform phenomena of the semiconductor LbL treated glass surfaces [Jung et al. 2004, Almog et al. 2011].

4. RESULTS

In that research work aimed window and glazing structures investigation were performed using finite element modelling, laboratory assays and on site measurements. The work done, systematically investigate the original aims and problems statements of window and window wall structure performances, focusing on the surface characteristics as well.

In the first part of this work, finite element method (FEM) was used to evaluate the overall heat performance of three different, widespread available window structure in Hungary standalone and built-in form: two wooden frames and one wood-alumina frame windows. The window structures were characterized properly by the FEM method. According to the results, it can be stated the heat transport difference between the 90 mm thick frame window and wood-alimuna frame window is negligible. The isotherms indicate that the temperature distribution is asymmetric in case of passive house window structure, and the outside cold air cools the central insulator. In case of the solid wood frame window the temperature distribution is more steady.

In the second part of this work the built-in, on-site window structures were measured and evaluated. The results indicate the inert gas filling is reducing in time and hence the heat performance of the window is also reducing. Up to date the investigation of inert gas filling and its effect was performed by destructive methods only, which resulted high cost and was not practical. Unfortunately the gas retard property is reducing by the time, but there is no other way to evaluate it. Spectral and mathematical transported figures were created from the on-site measurements indicating real heat transport phenomena.

Other notable result of the research is with LbL technique it was possible to create ultrathin coatings onto glass substrates that can reduce the *U*-value of window glass.

According to the results the nanocoatings did not reduce the transparency of the glass samples, furthermore, in a few cases the transmittance was improved in the visible region. In that near infrared region where the spectrophotometer could give results (760-1100 nm), the spectrum of the secondly thermal treated samples showed a transmittance drop from the wavelength of 1025 nm compared to the control sample. The LbL coated samples had lower *U*-values than the control window glass sample. After the second heat treatment the lowest *U*-value (2.817 $W \cdot m^{-2} \cdot K^{-1}$) was given by the sample coated with PAH/SiO_2/PAH/TiO_2/PAH/PSS/ZnO where the improvement was 22 % compared to the neat glass. Sample coated with PAH/SiO_2/PAH/TiO_2 showed a remarkable reducement in the *U*-value as well.

The surface energy was reduced after deposition of PAH/TiO_2 and PAH/SiO_2/PAH/TiO_2 multilayers without applying thermal treatment, whereas the other compositions made the glass substrate hydrophobic. After the thermal treatments the samples became hydrophilic. Treating the samples at 180 °C caused higher surface energy, most significantly in case of samples coated with PAH/TiO_2 and PAH/SiO_2/PAH/TiO_2/PAH/PSS/ZnO. After the second heat treatment at 500 °C the surface energies became even higher, in such a manner that after few days the surface energies was still unmeasurable since the water drops spread immediately on the surface and formed a thin layer. This strong hydrophilic characteristic was reduced in time, however in case of samples coated with PAH/TiO_2, PAH/SiO_2/PAH/TiO_2/PAH/PSS/ZnO and PAH/SiO_2 multilayers the loss of hydrophilic nature was less intensive. This result indicates that the LbL coating on window glasses can develop self-cleaning properties.

Lorenz simulation models clearly proved the activity of the semiconductors in UV region and the appearance of overall heat performance. According to the measurements carried out with methyl orange the samples coated with photocatalytic semiconductors are able to degrade organic contaminants at glass surface in presence of UV radiation and H_2O, thus the self-cleaning characteristic is might be achieved not only due the hydrophilic nature but the photocatalytic degradability as well.

5. MAIN CONCLUSIONS OF THIS RESEARCH WORK

1. Based on the finite element modelling it has been found that thicker window reveal did not result better insulation. Moreover, after a certain window reveal thickness the shape of the structure is as important as the window reveal thickness.
   According to the FEM simulation results the temperature distribution is asymmetric in case of passive house window structure, and the outside cold air cools the central insulator, which can degrade more rapidly.

2. Based on the finite element modelling and on-site measurements it has been found that the heat transfer performance of a window can be evaluated by non-destructive way. Spectral and mathematical transformed figures were created from the on-site measurements indicating the real heat transport phenomena.

3. The measurements showed that LbL technique is suitable for adsorbing ultrathin layers with semiconductive materals and polyelectrolyites which are able to enhance the transparency of window glass. According to the tests the nanocoatings lead to reduced transmittance in the near infrared region, and enhanced reflectance in the far infrared region.

4. Test results proved that the LbL nanocoatings (PSS/ZnO, PAH/SiO_2, PAH/TiO_2, ZnO/SiO_2, ZnO/TiO_2, ZnO/SiO_2/ZnO/TiO_2, PAH/SiO_2/PAH/TiO_2/PAH/PSS/ZnO, PAH/SiO_2/PAH/TiO_2) reduced the *U*-value of the glass samples (3 mm thick plate glass) compared to the control sample.

5. It can be concluded that without thermal treatment PAH/TiO_2 and PAH/SiO_2/PAH/TiO_2 coatings increased the surface energy, while the other coatings created a more hydrophobic surface compared to the control sample. The first and second heat treatment increased further the surface energies and the after weeks the coated samples lost a little from their hydrophilic nature.

   Discoloration of methyl orange solution proved the photocatalytic activity and the organic contaminant degradability of the LbL coatings adsorbed onto the surface of window glass containing semiconductive nanoparticles.

6. The Lorentz-Drude model seems proper in order to characterize the absorptive properties of semiconductive nanoparticles. The modelled and calculated values showed good agreement. Changing the absorptive properties of the window glass surface it is possible to influence the comfort attitude behind the window. The absorption was dominant against the reflections while the transmittance did not change.

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