PERFORMANCE CHARACTERISTICS OF WINDOWS IN THE COURSE OF THEIR SERVICE LIFE

Balázs BENCSIK[1], Zsolt KOVACS[1], Levente DÉNES[1]
[1] University of West Hungary Sopron
[2] H-9400 Sopron Bajcsy-Zsilinszky Str. 4

ABSTRACT

Performance characteristics such as air permeability and water tightness of windows deteriorate in the course of service life due to degradation of elements of the window system as a result of cumulative atmospheric effects and mechanical loads imposed on them by handling/operation. This phenomenon follows from the lack of a proper system of maintenance and from deficiencies of the design/manufacturing of the windows. Worsening of the performance leads to an increase of energy consumption as well as to an impairment of the occupants' comfort.

The objective of our study is to model the performance degradation of the windows as a function of service life. The problem relates models of product reliability using degradation data instead of failures. The steps to achieve our objective comprise identifying the most influential structural features/details of windows, surveying the change of these features/details with time of use, reproducing these changes on windows and testing them in laboratory. In these steps we use the methods of experimental design (DOE), reliability data collection and analysis, degradation model fitting.

Results obtained so far include the identification of the influence of weather stripping and hardware components on air tightness and water tightness, effect of extreme temperatures on sealing performance, as well as change of the window's performance as a function of the operation cycles.

pasztor.ildiko@rkk.uni-obuda.hu

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INTRODUCTION

The primary function of windows is to provide link between a closed comfort zone and the exterior environment while maintaining the thermal, acoustic and visual comfort of the occupants. Windows at the same time have a great impact on the energy balance of a building, in which respect expectations on performance characteristics defined in European standards are articulated in the different geographical zones. One of the requirements on performance characteristics is the rate of air permeability a window is supposed to comply with at the moment of its installation into the building structure. However, a window built in the facade is exposed to a number of degrading effects that will lead to a continuous change in their performance characteristics causing eventually their being unsuitable to fulfil their destiny. Unacceptable increase of air permeability will compromise other performance characteristics such as thermal and acoustical performance. Environmental factors causing degradation include ultraviolet radiation, daily and seasonal temperature fluctuation, rain and wind pressure, affecting the durability of window frame materials, sealing profiles and hardware systems alike. In the course of the use of windows hardware parts start to wear, sealing elements lose elasticity and/or move out from their right position. All these effects accumulate with time and contribute to a decrease of the reliability of performance characteristics by decreasing the probability of satisfactory operation. Clarifying the effect of these degrading factors on the air permeability will allow fitting a reliability model based on degradation data that can be used as the life distribution model of this performance characteristic. The final objective of our study is to establish this model and to apply the same for increasing the reliability of the air-tightness of windows in the course of their service life. In this paper we present results of air permeability tests performed in laboratory on sample windows in which sealing elements were varied and wearing of the hardware system was produced. As influences of the exterior environment, tests were conducted at different temperatures. Air permeability measurements as a function of pressure difference were evaluated in view of assessing the importance of changes in the condition of constitutive parts of window systems. When sufficient data will have been acquired with view to the timely development of these changes in real service conditions, model fitting will become possible.

EXPERIMENTAL

Laboratory air permeability tests were conducted on four sample wooden frame windows from four different manufacturers. The windows were of different sizes, operation and glazing system. Technical data on the four windows are given in table 1. Sample windows No 1 to 3 were tested to study the effect of the elastic sealing systems on air permeability. Sample 4. was used to investigate the influence of the environmental temperature on air permeability. The cross-section of the frame and casement were in all four cases identical to that shown in Figure 1.

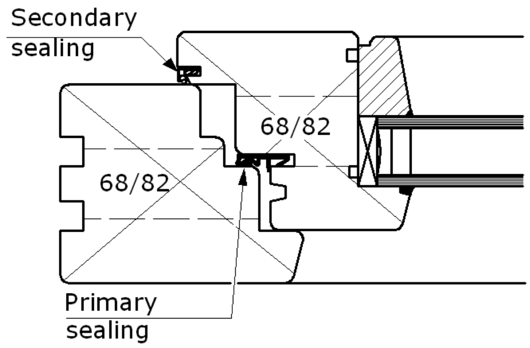

Figure1. Cross-section of window frame and casement profiles

Table 1. Technical data of the sample windows

No.	wood	dimensions [mm]	operation	Number of casements	Number of sealing profiles	Joint length [mm]	Number of fixing points	Profile depth [mm]
1.	Meranti	1230x1480	Tilt and turn	1	2	4914	7	68
2.	Sprucee	1780x2080	Tilt and turn	3	2	11640	9	68
3.	Spruce	1500x3000	Tilt and turn	3	1	13100	11	68
4.	Spruce	1230x1480	Tilt and turn	1	1	4914	6	68

Air permeability tests have been carried out according to the standard EN 1026:2011 in the laboratory of ÉMI Nonprofit Ltd. Budapest. In the course of the standard tests the outside face of the window frame was fixed with airtight connection to the boundaries of a chamber in which different levels of air pressure were produced between -600 Pa and +600 Pa while the air flow through the joints between the frame and casement are monitored by an air-flow meter and expressed as rate of flow per area of the window or per total joint length. The lower these values the better the air-tightness of the window.
When studying the effect of sealing profiles the experimental settings in Table 2 were performed on windows 1 to 3. In sample window No. 3 the inside sealing was missing therefore the change in the state of the middle sealing was studied only in a way that the original inside sealing was replaced by an original and unchanged one. All experimental settings were tested at a series of pressure levels of 50, 100, 150, 200, 250, 300, 450 and 600 Pa three times.

Table 2: Design matrix of experiments

setting	inner sealing	middle sealing
1.	yes	yes
2.	no	no
3.	yes	no
4.	no	renewed

With sample window No. 4 the influence of environmental temperature was investigated. The equipment used was of type Holten VHEPC comprising an air preconditioning appliance capable of maintaining the testing air temperature at constant values between minus 40 °C and plus 50 °C. In the course of the air permeability tests the stipulations of the standard EN 1026:201 were applied except for the temperature of the testing air. The window in this case was tested for outside compression only. Before starting the tests, hardware adjustment and a checking of integrity of the sealing profile were performed then air permeability was tested at 23 °C ambient temperature in three repetitions. That was

followed by heating the pressure side air to 45 °C. When the pressure chamber attained this temperature the air permeability of the window was tested in three repetitions, than keeping the elevated temperature of the pressure side two additional tests were conducted at 1 hour intervals. Following these tests the sample window was left to recondition for 18 hours while the window and the testing equipment cooled down to 23 °C. Before performing the measurements at low temperatures the air permeability of the window was again tested at 23 °C than the exterior side of the window as well as the testing equipment was cooled down to minus 10 °C. Attaining this temperature air permeability was tested in three repetitions, followed by cooling to minus 20 °C at which temperature air permeability was again tested three times.
After several days of recovery, cyclic wind load pressure tests according to the standard EN 1191 combined with cyclic operation (opening and closing) test were conducted on sample window 4. Before starting the cyclic tests a new reference air permeability test was conducted in three repetitions. Steps of the cyclic test are summarised in table 3. As an initial step the window was loaded with 500 cycles of compression and decompression, maintaining the nominal wind load values for 3 seconds than changing the direction of the load, simulating wind gust effects. Wind gust loading was followed by repeated opening and closing of the window in high number of cycles. This hardware fatigue test was performed in automatic equipment that opened the casement in turn position, than closed it, than opened it in the tilt position than closed it to make a full cycle of operation. After a preset number of cycles air permeability was tested again in the standard way.

Table 3: steps of the fatigue test

Steps	Testing load
1.	500 x (-500Pa)-(+1000 Pa) wind gust
2.	2500x opening and closing cycle
3.	air permeability test
4.	500 x (-500Pa)-(+1000 Pa)wind gust
5.	2500x opening and closing cycle (total 5000 cycles)
6.	air permeability test
7.	500 x (-500Pa)-(+1000 Pa) wind gust
8.	2500x opening and closing cycle (total 7500 cycles)
9.	air permeability test

RESULTS

Test results are shown in tables 2 to 6. Air permeability measurements against pressure difference levels were plotted on a logarithmic scale along with the 95% confidence limits of measurements. Measured values were expressed as air flow rate per window surface area as stipulated in the relevant standard EN 12207:2001. In Figure 5 air flow values are given as mass flow values corresponding to the test air temperature rather than in m^3/hm^2 since the density of air is a function of temperature and the same volumetric flow at a low temperature corresponds to a larger amount of air than at a higher temperature. Adjustments were made by the use of the equation below:

$$\dot{m}_x = \rho_x \cdot \dot{V}_x \qquad \text{[kg/h]} \qquad (1)$$

where: $\dot{m}_x$ - mass flow of a gas of given temperature [kg/m^3]

ρ_x - density of a gas of given temperature [kg/m^3]

$\dot{V}_x$ - volumetric flow [m^3/h]

Results of the experimental settings of individual sample windows were evaluated by analysis of variances (ANOVA). Significance of the deviations of results was also examined by using Tukey test of significance at 95% confidence level.

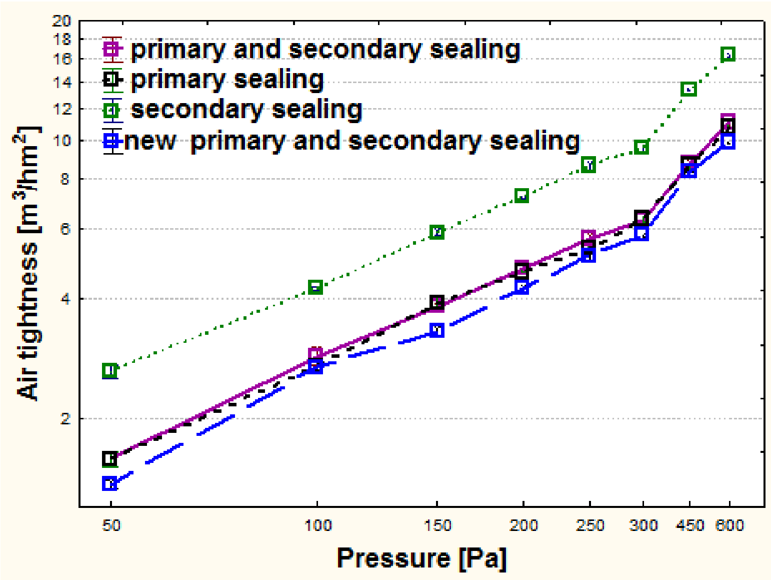

Figure 2: Air permeability plots of window No. 1. with different sealing configurations

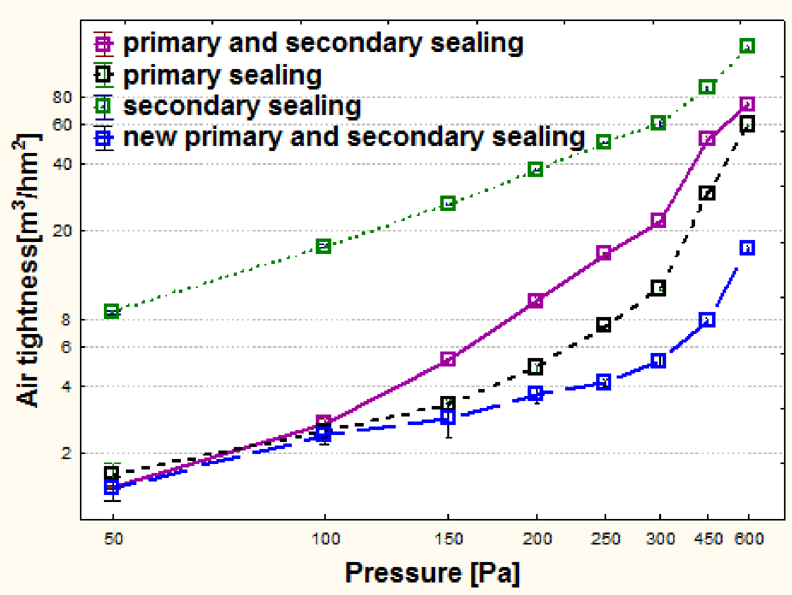

Figure3: Air permeability plots of window No. 2. with different sealing configurations;

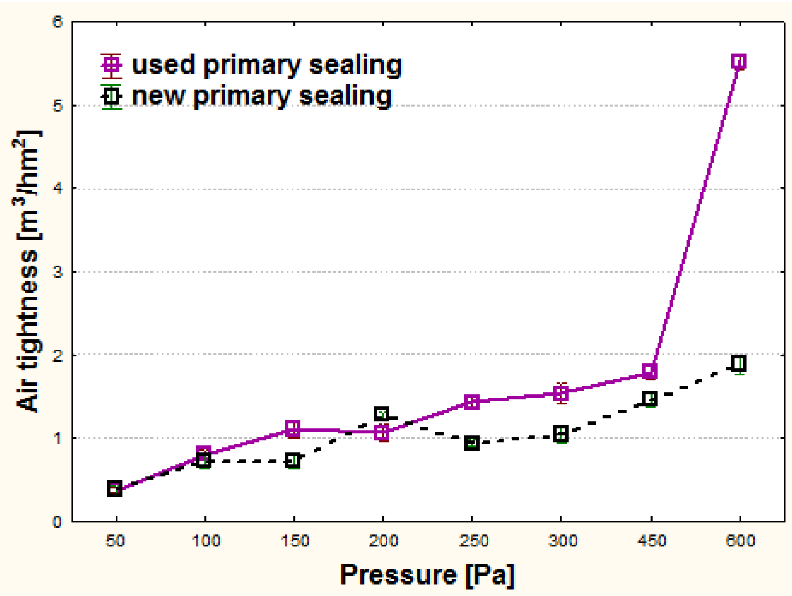

Figure 4: Air Fpermeability plots of window No. 3. with different sealing configurations

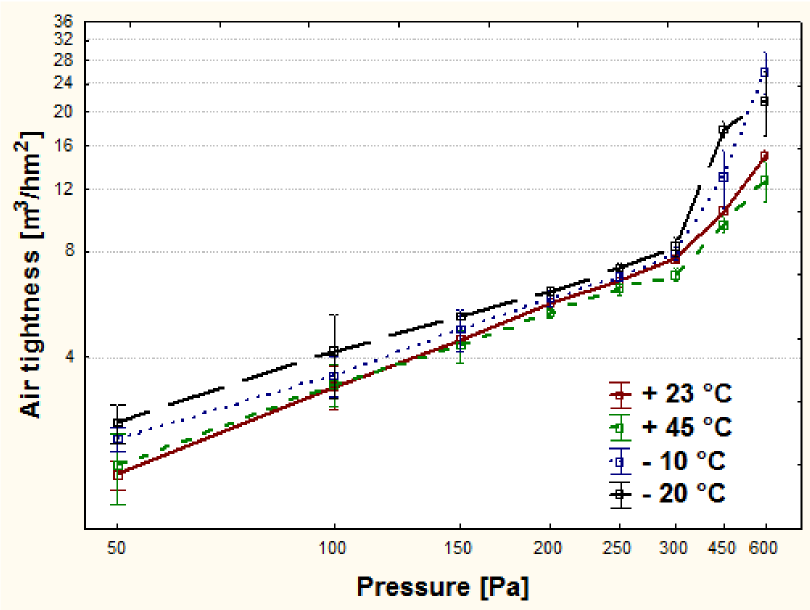

Figure 5: Air permeability plots of window No. 4. For different temperature levels of the pressure chamber

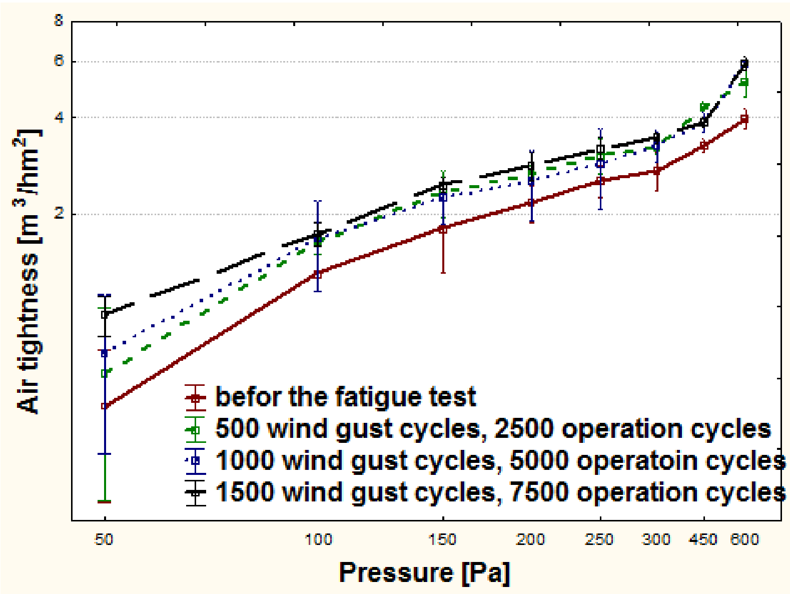

Figure6: Air permeability plots of window No. 5. for different cycle numbers of fatigue test

DISCUSSION OF THE RESULTS

On the basis of test results it can be established that the secondary inner sealing has no important influence on the overall air permeability behaviour of windows. Moreover, taking into account its generally inherent vulnerability due to the location where it is fixed, it can be omitted with low risk of compromising air tightness. The effect of the middle sealing in the individual windows tested exhibited itself of varying importance. It was found that in the case of windows of relatively small size and satisfactory closure the state of the middle sealing has a negligible effect only on the air-tightness, while in windows of larger dimensions and/or of multiple casements where deformation of the structure under wind load may be significant, the state of sealing becomes important. At low pressures when the contact between the frame and the casement(s) is tight sealing profiles having been used for a longer period are still able to satisfactorily seal against air flow. When increasing testing pressure the growing deformation of the frame and casements results in gaps of increased size. A sealing profile that would be able to cover tightly the enlarged gap, after sustained use will lose its resilience leading to a sudden increase of air permeability after a given amount of deformation of the tested window system under wind pressure.

Figure 5 illustrates the air permeability results of sample window No. 4 at different testing temperatures. It is evident from the figure that the best air tightness was attained at 45 °C. However, Tukey tests performed show that temperature as an environmental factor has significant effect on air permeability at lower temperature levels only. The explanation for this finding can be found in the fact that the material of the sealing profile becomes brittle at low temperatures rendering the profile unsuitable to cover gaps that appear with increasing pressure. Furthermore, gap increase is probably contributed to by a shrinkage of cross-sections due to lowering the temperature.

In the course of fatigue tests air-tightness of the windows deteriorated with increasing numbers of cycles. Cyclic operation test was performed up to 7500 cycles. It can be stated that significant drop in performance occurred in the course of the first 2500 cycles; further cyclic testing however has not produced important changes of air permeability. This finding allow us to conclude that in the course of an initial cyclic operation repeated up to a certain cycle number the parts of the hardware system get in a stable working state determining the tightness of closure that may not change for a longer use (i.e. relatively high number of operation cycles).

CONCLUSIONS

From the results of tests it follows that air permeability of windows in the course of their service life is changing unfavourably as a consequence of both environmental effects and mechanical effects due to a number of operation cycles. Among the constitutive elements of a window system the state of the middle sealing profile has the most important effect on air tightness.

With varying environmental temperature both the dimensions and the rigidity of the structural parts change, that is why air permeability performance of built-in windows at changing temperature conditions is not identical to that measured with standard laboratory method. Operations in the course of service life, especially with no or inadequate greasing will lead to excess wearing of the closing elements in the hardware system, resulting a decrease of the tightness of contact in closed position. In buildings, these effects on windows will generally added together and their consequences accumulate, resulting in continuously increasing degradation of the performance characteristics. In order to be able to enhance the reliability of the windows' performance characteristics it is necessary to know how the changes in the window elements contribute to a life distribution model that can be fitted to the degradation of the performance characteristic in question. The continuation of our research will be focussed on the completion of the degradation model for the windows' air permeability. This model will relate changes resulting from accumulated use (operations) and environmental effects to degradation of air permeability. Than we may look for the possibilities of mitigating the changes that occur in parts of the window system in the course of service life either by modifying their design, or through expedient maintenance.

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