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Lifetime performance evaluation of stick and panel curtain wall systems by full-scale testing

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HIGHLIGHTS

- Mandatory tests are inadequate to evaluate lifetime performance of façade systems.
- Full-scale tests can provide realistic information about system performance.
- Stick system might be fragile than panel system under similar extreme conditions.
- Thermal cycling test is significant for lifetime performance evaluation.
- Air and water infiltration are the most common problems in curtain wall systems.

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ABSTRACT

This study presents stick and panel curtain wall systems' lifetime performance comparison by conducting full-scale testing according to a proposed test method. The procedure is based on Turkish standards and supported by CWCT. Besides weather tightness, wind and seismic resistance tests, thermal cycling are included to the procedure in two-stages between −10 °C and +50 °C considering temperatures in 20 years in Istanbul. Results showed that stick system might be more fragile than panel system under the same conditions. This study is thought to be a leading work in lifetime performance assessment of such curtain wall types by considering specific local conditions.

1. Introduction

Curtain walls are mostly preferred systems for multi-story buildings as they provide advantages such as lightness (especially for seismically vulnerable areas), ease of construction, weather tightness performance, accommodate of various movements, comfortable internal environment and aesthetics [1–4]. Stick systems are widely used in low-to-medium rise buildings and are assembled on site with numerous components such as anchors, mullions, transoms, infill panels and sealants. Thus, workmanship quality has a crucial role for system performance [5]. Panel systems, on the other hand, vary from stick systems with their manufacture and assemble processes. These systems are manufactured at factory as units which are assembled on site providing less worksite labor than stick systems. Moreover, panel system components are assembled under stable ambient conditions without being affected by weather conditions increasing system quality. This would lead to the known fact that weather tightness performance of panel systems might be better than stick systems. On the other hand, due to different assembly and manufacture processes, the overall cost of panel systems is generally higher than stick systems [6,7]. Since both systems are the most common systems and widely used in construction market, building type, users, number of stories, built environment, surrounding area, expected performance criteria, and climatic conditions should be considered for selecting the most suitable system for a specific project.

Many researches have been conducted so far on curtain wall systems since they constitute a large part of a building cost and related new technologies have been developing. By considering the complexity of curtain wall systems in recent years, Gonçalves and Jutras, suggest that performance assessment before installation process be given crucial importance for preventing unwanted

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and costly issues during systems' lifetime [8]. Kazmierczak, reviewed the curtain walls by focusing on design problems and solutions with regard to their basic classification systems and challenges in their design and construction. Moreover, failures and associated measures were discussed for both stick and panel systems [9]. McCowan and Kivela presented the failures and problems on glass and aluminum systems by conducting curtain wall failure observations. In that study, air and water leakage, glass cracking and fogging glass are defined as commonly encountered problems. Analysis of the systems before the construction process, mock-ups tests were conducted to confirm the quality of workmanship and importance of the sealants in system performance [10]. Becker emphasized on the importance of the workmanship during installation. Air tightness performance of the curtain wall system was improved by monitoring the construction process of laboratory mock-up test. While the selected system barely meets the requirements of the EN 12152 level A2, system air tightness performance was improved to level E after the remedial action on the detected points during construction process [11].

Although thermal performance of the systems can be defined by simulation, real thermal performance of the system may vary with simulation results. Thus, the correlation between mock-up test (thermal cycling) and simulation were evaluated in No et al.'s study to understand the potential reasons of differences between two methods. Convective film coefficient used in simulation provides more conformity with mock-up test results [12]. An investigation was conducted into structural performance of curtain wall systems in Huang et al.'s study and seismic demand and experimental methods about the seismic issues, damage mechanism, and performance based curtain wall design were evaluated and future developments were presented [4]. A study on curtain wall systems was conducted to improve poor performance parameters of existing curtain wall systems in Cuce et al.'s study. In that study, performance of two curtain wall systems with ordinary and novel glasses are evaluated experimentally according to thermal insulation, indoor lighting, energy saving, ultraviolet light penetration criteria. Novel glass curtain wall system showed more ultraviolet light blocking capacity, decreased building heating and cooling demands, and prevent the excessive thermal radiation compared to ordinary glass [13]. A new curtain wall system manufactured with laminated timber frame was proposed in Buljan et al.'s study as an ecological friendly system, which may provide equal or better thermal performance than aluminum curtain wall systems and test results showed that timber framed system has better energy performance aluminum frame systems [14]. The effect of mullion materials on environment and health was evaluated over curtain wall system life cycle in Azari-N and Kim's study and it was found that glulam timber has minimum effect when compared with extruded aluminum and carbon steel [15].

Water leakage has been one of the most encountered problems for buildings and therefore dynamic water test results are significant performance indicators. The aim of Matthews et al.'s study about dynamic water test was to establish wind conditions produced on a curtain wall specimen by wind generator for comparison with standard estimates of wind velocity and pressure to determine whether the test could be considered a meaningful representation of a real environment or not [16]. In Lee et al.'s study, a two-phase experimental work was carried out. In the first phase, calibration of wind generator was conducted following AAMA 501.1-05 and in the second phase dynamic pressure distribution was handled for the surface of the curtain wall systems [17]. Warner presented the standard testing sequence and overview of test protocols by considering the importance of exterior mock-up testing for performance evaluation of glazing systems and exterior walls under the effect of earthquake and extreme climatic conditions. In that study, thermal cycling test was defined as a significant test for long-term performance [18]. A comparative study was conducted on two identical unitized curtain wall systems by full scale testing method at Ilter et al.'s research. A fatigue process was applied on one of the specimens in addition to standard test procedure to investigate the long-term performance of the systems and to understand the effect of fatigue process on system performance [19].

Similar to any kind of building system, curtain wall systems' lifetime is intended to be equal to building lifetime, which can be approximately assumed to be 30–50 years [20]. Although curtain wall system manufacturers usually give maximum 20 years guarantee for their systems, various deficiencies might occur because of mechanical, electromagnetic, thermal, chemical or biological agents during this period. In addition, lifetime process, building-façade interaction and external factors may cause deficiencies on the systems as well. These reveal that systems' lifetime performance is one of the current crucial topics to be investigated in façade research and practice [7,21]. Although, lifetime performance one of the crucial topics for façade systems, studies about lifetime performance is scarcely/rarely investigated in literature (i.e. Ilter et al. and Matthews et al. etc.). This study serves as an important step/way of using/proposing a systematic procedure with full-scale experimental testing which requires quite high cost and labor-intensive study.

In a previous study conducted by the authors, curtain wall systems deficiency and failures of existing residential and commercial multi-story buildings constructed in Istanbul between 1996 and 2012 years were investigated and classified. The study showed that most of the deficiencies were observed on stick curtain wall systems. Aesthetics, weather (air/water) tightness and structural issues (e.g. strength loss, excessive deformations, breaking, fracture, etc.) were the most common problems observed on curtain wall systems on the observed buildings in Istanbul [7]. Another previous investigation was conducted together with the façade test center in order to determine the most common curtain wall system types for mock-up manufacturing. In the scope of the study, thirty-six building's façade systems were investigated. Twenty-one of these buildings were panel systems while fifteen of them were stick systems.

Façade lifetime performance is not only important for users but also it is a significant prospect for all stakeholders who are involved in façade process. BS 7543 [22] proposes three methods to obtain preliminary information about building or building components lifetime performances. According to this standard, the first method is to use past performance data to gain information about service life of the systems; such as time to repair, failure and source of deficiencies. In the second method under expected or specified conditions degradation of the system can be modeled physically [22]. Mandatory façade performance tests, such as air permeability, water tightness and wind resistance, which are applied to curtain wall full scale mock-ups, can help to gain prior information about system's performance before assembly process. However, passing these tests does not guarantee the lifetime performance of the system to be the same as the test results [23]. The last method is to predict lifetime performance of the systems by using available national data sets prepared by experts and professionals [22].

This study focuses on lifetime performances of stick and panel systems by using 1:1 scale performance tests according to the proposed test method. A new test procedure including the aging test is proposed and conducted to show the importance of the thermal cycling test for lifetime performance evaluation and to further clarify the effects of aging test on stick and panel systems performance during their lifetime. Test results and lifetime performance of the systems are compared to each other. Related curves are generated to show the performance variation. Also, a curve-fitting procedure