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Critical analysis and innovation proposals to the heat and thermal shock test method of the Brazilian Standard NBR 15575 (2013)

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ABSTRACT

The tests of Brazilian Standard NBR 15575: 2013 are part of the knowledge of the civil construction industry, but the heat and thermal shock test is innovative and does not have a consolidated history. The research objective is to analyze the testing critically and present proposals based on data meta-analysis. Results showed that the test is very inaccurate in describing the procedure and equipment. This study proposed adjustments and innovations in the test to provide more reliable results, but it does not make propositions regarding visual inspection and the number of cycles. The study concluded that the lack of information on the testing has direct responsibility for the results and that the suggested proposals have the potential to be incorporated.
Keywords: heat action and thermal shock; durability; evaluation of building performance.

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Contribution of each author
In this work, author L. S. Lorenzi contributed with the original idea, experimentation, development of a model, data collection, writing of the work, and discussion of results. The author K. J. Stein contributed with the experimentation, data collection, writing of the work, and discussion of results. The author L. C. P. Silva Filho contributed with the original idea and discussion of results.

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Análise crítica e proposições de inovação ao método de ensaio de ação de calor e choque térmico à luz da ABNT NBR 15575 (2013).

RESUMO

Os ensaios da ABNT NBR 15575:2013 fazem parte do conhecimento do setor da construção civil, mas o ensaio de ação de calor e choque térmico é inovador e não possui um histórico consolidado. O objetivo da pesquisa é analisar o ensaio criticamente e apresentar proposições. O método de pesquisa é a meta-análise de dados. Os resultados demonstraram que o ensaio é bastante impreciso na descrição do procedimento e do equipamento. Foram propostos ajustes e inovações no ensaio para proporcionar resultados mais fidedignos, porém não foram realizadas proposições quanto à inspeção visual e aos números de ciclos. Conclui-se que a falta de informação do ensaio tem responsabilidade direta nos resultados e que as proposições sugeridas têm potencial para serem incorporadas.

Palavras-chave: ação de calor e choque térmico; durabilidade; avaliação de desempenho de edificação.

Análisis crítico y propuestas de innovación al método de ensayo de acción de calor y choque térmico a luz de la ABNT NBR 15575 (2013)

RESUMEN

Los ensayos de la ABNT NBR 15575:2013 hacen parte del conocimiento del sector de la construcción civil, pero el ensayo de acción de calor y choque térmico es innovador, y no posee un histórico consolidado. El objetivo de la pesquisa es analizar el ensayo críticamente y presentar propuestas. El método de pesquisa es meta-análisis de datos. Los resultados demostraron que el ensayo es bastante impreciso en la descripción del procedimiento y equipos. Fueron propuestos ajustes e innovaciones al ensayo para proporcionar resultados más fidedignos, sin embargo, no fueron realizadas propuestas en cuanto a la inspección visual y a los números de ciclos. Se concluye que la falta de información del ensayo tiene responsabilidad directa en los resultados y que las propuestas sugeridas tienen potencial para ser incorporadas.

Palabras clave: acción de calor y choque térmico; durabilidad; evaluación de desempeño de edificación.

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1. INTRODUCTION

The Brazilian civil construction industry is in a period of great transformation in the technological area. The increase in the use of new materials, especially in residential buildings, and ABNT NBR 15575 (2013), henceforth NBR 15575, are promoting positive and significant changes in the sector. There is an increase in the interest of the civil construction market in knowing the behavior of the construction systems of buildings in use. This period provides a demand for testing and analysis of results. It also reflects an increase in the laboratory demand for services and technical assessment institutions, as well as the involved standard analysis.

Standards are not absolute nor perfect, so they need updates to keep up with the speed of technological changes (Borges, 2012). The evaluation methods and parameters established in standards, mainly in NBR 15575, must be adjusted over time (Thomaz, 2012 and 2013). Due to the little national experience in experimental performance tests to characterize the behavior of construction systems, the methods from countries with more experience in this type of research served as a basis for the Brazilian standard. It is noteworthy that, although the method is adequate, the conditions of these countries are different from the Brazilian reality, in which there is a lack of infrastructure for conducting tests. This fact was already alerted by Mitidieri Filho (1998) when he explained that methodologies for performance evaluation were brought from experiences by developed countries, where conditions are very different, giving rise to strict criteria for the existing reality. Another factor that the author draws attention to is related to the tests and parameters established in Brazil in the 1980s, aimed at building systems with conventional technology, excluding, to a certain extent, innovative building systems.

The use of conventional systems as a reference and by comparison to judge innovative systems is usual; however, it is not a correct practice (Mitidieri Filho, 2007). NBR 15575 has some parameters that may be dissociated from the Brazilian reality, and so adjustments to the standard are necessary. Nevertheless, it is essential to start implementing the standard, even if limiting parameters below the international minimums are used (Thomaz, 2013).

The lack of a significant volume of tests and studies on the representability of parameters as to the results obtained, the correlations between test procedures, and expected ranges of results are factors that call into question the tests and parameters established in NBR 15575. Brazil does not have enough tests to characterize construction systems, whether they are innovative or not. In this context, several institutions have developed or adapted test procedures for performance evaluation, specifically the Institute for Technological Research (IPT) and some university laboratories. This attitude is encouraged by Thomaz (2013) and Villas Boas (2013) when they express that there is much to be improved in the requirements, criteria, evaluation methods, and parameters established in NBR 15575 since many construction systems are not contemplated by the standard yet.

A critical analysis of the tests to assess the performance of buildings, based on NBR 15575, concluded tests in the area of safety regarding structural performance have a consistent history but still need improvement. The other performance tests regarding safety, fire performance, and use and operation are in a maturation phase, in which they are beginning to have the deserved prominence. Habitability tests, acoustic performance tests, and water tightness tests are carried out more often and provide valuable information about building performance. As for the other building performance tests recommended in NBR 15575, there is no significant history that stands out, mainly when used to evaluate the elements that make up the construction systems. Among these tests, the heat and thermal shock test is considered new and, therefore, has no consolidated history (Lorenzi, 2013).

Intending to take advantage of the experience related to building performance tests, accumulated over the years by LEME / UFRGS (Laboratory of Testing and Structural Models at the Federal University of Rio Grande do Sul), this work carried out an evaluation of the procedure and the

parameters of the heat and thermal shock test for external vertical sealing systems (EVSS).
The intention was to identify possible adjustments and innovations that could be applied to the testing, incorporating advances in procedures and allowing more accurate results regarding the behavior in the use of buildings. The adjustment of some acceptability parameters also provided a more coherent and fair assessment of the systems.
So, the main objective of this work was to perform a critical analysis of the heat action and thermal shock test, established and recommended in NBR 15575 for EVSS to evaluate the behavior regarding durability during the useful life and to present advancement proposals procedure and acceptability parameters.

2. BUILDING PERFORMANCE ASSESSMENT

A set of different instruments, such as theoretical analyses, simulations, experimental tests, and technical inspections, is the basis for the performance evaluation proposal of NBR 15575. Each of them contributes some way to assess whether the testing meets the requirements established for each performance criterion.
The culture change in the civil construction chain in using evaluation methods, more precisely tests to characterize the behavior of construction systems, can occur at two different times: the first concerns the use of tests in buildings ready to solve conflict situations between developer/builder and user. The second refers to the tests performed to characterize the behavior of the construction systems in use that are or will be applied in buildings (Borges, 2008). The European experience in the area indicates the culture related to the concept of building performance increases the carrying out tests, and this scenario is projected for Brazil in the coming years, increasing the demand for this type of testing. However, there may be significant delays in this scenario due to the limited laboratory capacity installed in the country (Lorenzi, 2013).
The performance assessment of a construction system aims to identify if the building production can use these systems and if they are capable of meeting performance requirements. This evaluation is only possible when working with a multidisciplinary team, experienced in the area, and if the structure to carry out this assessment is available. These conditions make possible to adjust or create new performance standards for construction systems, if necessary (Becker, 2001).
The standardized methods and procedures that allow reproducibility and verification regarding the fulfillment of building performance requirements should also be highlighted. This step is very relevant when it comes to analyzing the feasibility of using a construction system (Mitidieri Filho, 2007).
Brazil is in the expectation phase regarding the evolution and improvement of the tests recommended in NBR 15575, and to assist in this task, it is necessary to carry out critical analyzes on their practice, identifying gaps, and promoting adjustments that allow advances in testing methods and procedures. The moment is for consolidating practices and discussing methods and procedures to assess building performance, with attention to tests and acceptability parameters.

2.1 Heat and thermal shock test

The heat and thermal shock test to assess the durability requirement is presented in NBR 15575-4, internal and external vertical sealing systems (IEVSS) for residential buildings. The purpose of this test is to analyze the behavior of the EVSS when subjected to successive cycles of heating by heat source and cooling by water jets. The idea is to simulate the stress that buildings suffer during their useful life through the variation in temperature and humidity associated with the action of rain on the heated element (wall). The heat and thermal shock test is one of the accelerated aging tests used to assess the potential behavior of the EVSS in use. The test promotes an increase in the frequency of the occurrence of agents that induce deterioration. In this case, the deteriorating agent is the abrupt change in temperature on the surface of the element, when subjected to thermal shock. This situation occurs when, for example, the building's façade is hit by rain suddenly, after a day of much sunlight (Fontenelle, 2012).

A notorious aspect of the study of façade durability is its behavior when facing sudden heating and cooling cycles. The temperature difference between the surface and its interior can cause stresses of high magnitude, deteriorating facade system, in particular, light systems (with little thermal inertia) and those composed of several layers with non-homogeneous elements (Oliveira et al., 2014). When the temperature variation is sudden, the load rate on the element is high. However, the propagation of thermal deformations on the same element depends on its response speed until it reaches balance (Esquivel, 2009).

The heat and thermal shock test established in NBR 15575-4 consists of applying ten successive heating and cooling cycles for each specimen representative of the EVSS. The surface exposed to the heat must remain at temperatures between 80 ± 3 ° C, for one hour. After this period, water is sprayed on the heated surface until it reaches temperatures in the range of 20 ± 5 ° C. The test procedure requires a specimen with a variable extension (width) between 1 meter to 1.40 meters and the height of a wall. The specimen is placed on a fixing device by the lower and upper edge.

The recommendations of NBR 15575 regarding the performance evaluation of EVSS take into account the degradation caused by thermal shocks, such as cracks, failures, detachment, blistering, deterioration, among others, resulting from thermal expansion, retraction, and expansion. Also considered in this evaluation is the maximum horizontal displacement parameter (h /300), where h is the height of the element. A deflectometer is positioned on the opposite side in the center of the element to measure the horizontal displacement.

Among the national and international standards related to the thermal shock in EVSS, there are some divergences regarding categories and parameters. For example, the heating temperature for the exposed surface of the EVSS recommended by NBR 15575-4 differs from the ETAG 0004 (2008), which establishes a temperature of 70 ± 5 ° C and ISO 8336 (2009) and ASTM C1185-8 (2012) standards which establish a temperature of 60 ± 5 ° C. The measurement of surface temperatures is another divergent point. In the Brazilian standard (NBR 15575), the measurement is performed by thermocouples, which are coupled directly on the surface of the specimen. On the other hand, in the American standard (ASTM C1185-8), the thermocouples are not fixed directly on the specimen. They are attached to small metallic plates, painted in black, which are fixed on the surface of the specimen (Oliveira et al., 2014).

Table 1 summarizes the differences in parameters adopted in Brazilian standards and other testing methods concerning some of these aspects previously explained.

Table 1. Differences in parameters adopted among Brazilian standards and international testing methods.

Category	**Parameters**	**Detalhamento dos parâmetros**		
		NBR 15575-4 (ABNT, 2013b)	**C1185-8 (ASTM, 2012) and ISO 8336 (ISO, 2009)**	**ETAG 004 (ETAG, 2008)**
Heating	Test temperature measurement method	Direct measurement, using thermocouples positioned on the heated specimen surface	Indirect measurement, measured on the reference specimen/black metal plate	Direct measurement, using thermocouples positioned on the heated specimen surface

	Time to reach maximum heating temperature	Not established	Not established	1 h
	Maximum test temperature	80 ± 3 ° C	60 ± 5 °C	70 ± 5 °C
	Dwell time in the heated phase	1 h	2 h 55 min	2 h
	Admitted temperature variation between center and specimen edges	± 3 °C	Not established	Not established
Cooling	Water temperature	Until reaching the surface temperature of 20 ± 5 ° C	≤ 30 °C	15 ± 5 °C
	Amount of water	Not established	3.79 l/min	≥ 1.0 l / m² min, which is equivalent to approximately 6.0 l / min
	Sprinkling time	Until reaching the surface temperature of 20 ± 5 ° C	2 h 55 min	1 h
	Distribution over the surface	Uniform	Uniform	Uniform
	Temperature after specimen cooling	20 ± 5 °C	Not established	Not established
Cycles	Time of each cycle	Approximately 6 h, depending on the composition of the wall	6 h	6 h
	Number of cycles	10	25	80
	Interval between cycles	Not established	5 min	2 h
Specimen	Dimension	≥ 3.0 m² (1.2 m x 2.5 m)	≥ 3.5 m²	≥ 6.0 m²
	Restriction of edge movement	No restriction	Restricted	No restriction
	Surface color	Not established	Not established	Not established

Source: Oliveira et.al. (2014)

The interpretive analysis of the building performance tests established in NBR 15575 carried out by Lorenzi (2013) originated a mapping containing tests x buildings x interpretive analysis criteria, serving as a basis to identify the tests to be critically analyzed, concerning the interpretation, procedures, equipment, and parameters. This mapping identified the test that needs to be improved is the heat and thermal shock test.

Oliveira et al. (2014) also proposed improvements for the heat and thermal shock test. These changes should be applied to SVVE consisting of light elements (≤ 60kg / m²), considering new parameters, procedures, or conditions for carrying out the test. Table 2 presents a summary of the advanced proposals for the heat and thermal shock test.

Table 2. Advanced proposals for the heat and thermal shock test.

Category	Lorenzi (2013)	(Oliveira et.al., 2014)
Heating	-	80 ± 3 ºC EVSS in a usual situation 60 ± 3 ºC EVSS in a particular situation
	Variable time according to EVSS composition	At least 1 hour for the EVSS to reach the maximum temperature
	-	Heating exposure increased from 1 h to 2 h
	The heat must warm the entire surface of the specimen	Identify distortions between the center and the edges of the specimen
	The specimen must have a homogeneous temperature	W / m² control
Cooling	Keep the water cooled to the temperature of 20 ± 5 ºC	Control the temperature of the cooling water
	Cooling time, sprinkling, and speed with which the temperature variation occurs	Cooling time, sprinkling, and speed with which the temperature variation occurs.
	Cooling water at a constant temperature	The temperature control method according to the standardized temperature
	Constant and uniform water sprinkling on the specimen, controlling the water pressure	Surface distribution
	Reuse of the water	-
Cycles	Successive cycles (no interval)	There must be an interval between cycles
Specimen	Minimum width 1.0 m to 1.40 m	Minimum width 2.40 m
	Height 2.50 m	Height 2.50 m
	All the details of the EVSS	All the details of the EVSS
	Side constraint	Side joining
	Supported on the bottom and restricted on the top	Supported at the bottom and articulated at the top
	-	External face color: absorbance ≥ 0.5 to reach 80 ºC faster
Radiant panel and water spray equipment	Electrical resistance radiation	Electrical resistance radiation and ultraviolet lamps
	The radiant panel area should be the same as the specimen area	-
	Possibility of inspection at each cycle	-

Horizontal displacement parameter	Decrease the limit for horizontal displacement by 50%	-
	Add the residual horizontal displacement	-
Rainwater tightness test	Before and after the heat and thermal shock test	Before and after the heat and thermal shock test

The fixation of the specimen during the test is one of the relevant points to be incorporated into the testing. The containment of the specimen must restrict the expansion or contraction of it in the length direction, allowing free vertical movement and transverse displacement, and offering no restriction on the formation of the arrow due to the temperature gradient in the wall section. These considerations should be applied by systems that present significant displacements due to dimensional variations, caused by the effect of temperature and humidity. In cases such as these, Fontenelle and Meditidieri Filho (2016) indicated the contention of the specimen.

The heat and thermal shock test does not present a single result for all construction systems. Its boundary conditions control the element's response to thermal shock. That is why the external restrictions on the free deformation of the specimen can aggravate the stress state. If the exposure to the heat flow is symmetrical over the entire surface of the specimen, the heat transfer will occur until it reaches thermal equilibrium, in other words, the temperature will be the same throughout the solid (Esquivel, 2009).

3. METODOLOGY

The experimental strategy was carried out based on the advance propositions recommended by Lorenzi (2013). Altogether, the study subjected the samples to a total of 280 cycles. Ten out of 12 specimens were exposed to 220 thermal cycles. On the other two, only 60 thermal cycles were applied. The strategy focused on critically analyze the advancement proposals to improve the test results.

The advancement propositions incorporated were:

- Heating time according to the construction system;
- The water used during the test should be kept in a reservoir at 15 to 25ºC;
- Cooling time according to the construction system;
- Cooling water always in the temperature range between 15 to 25ºC;
- Uniform and constant water spray (3 l/m²/min), the water spray pressure should have no interference in the construction system;
- Reuse of test water;
- Successive cycles, no interval;
- Visual inspection at each cycle;
- Width of the specimen 1.20 m;
- Height of the specimen 2.50 m;
- Radiation by electrical resistances;
- Execution of the rainwater tightness test before and after the thermal shock test.

The following criteria was the basis for the analysis of the propositions:

- **Applicability**: This criterion concerns the applicability of the test in terms of the minimum dimensions and position of the specimen and its instrumentation;
- **Feasibility**: This criterion concerns the execution of the test and the possibility of reproducing the proposals;

- **Reliability and representability of the results**: This criterion has the precept to recognize that the propositions reproduce in the best way the real situation to which the systems are subject;
- **Suitability**: This criterion is associated with the suitability of the test method to the different construction systems.

4. RESULTS

The results are presented in Table 3, which shows how each advanced proposal for the heat and thermal shock test was incorporated into it, thus reaching expectations.

Table 3. Results of the incorporation of the proposals to improve the heat and thermal shock test.

Category	Proposals	Applicability	Feasibility	Reliability and representability of the results	Suitability
Heating	Heating time according to the construction system	OK	OK	1*	1*
Cooling	Keep the temperature of the water stored in the reservoir between 10 to 20ºC	OK	OK	OK	OK
	Cooling time according to the construction system	OK	OK	2*	2*
	Keep the temperature of the cooling water between 10 to 20ºC	OK	OK	OK	OK
	Uniform water spray (3 l/m²/min) Constant and with pressure without interference in the construction system	OK	OK	OK	OK
	Reuse of the water	OK	OK	OK	OK
Cycles	Successive cycles (no interval)	OK	OK	OK	OK
	Visual inspection at each cycle	3*	3*	3*	3*
Specimen	Specimen width 1.20 m	OK	OK	OK	OK
	Specimen height 2.50 m	OK	OK	OK	OK
Equipment	Electrical resistance radiation	OK	OK	OK	OK
Tightness	Application of the rainwater tightness test before and after the thermal shock test	OK	OK	OK	OK

1*, 2*, and 3* - New advances propositions to the test.

Based on the accumulated experience in the application of the heat and thermal shock test carried out with radiant panel equipment, this study observed that the hot air convection printed very high temperatures at the top of the sealing system.
The air convection helped to homogenize the temperatures in the specimen, spreading the radiation that was only at the bottom, as shown in Figure 1.

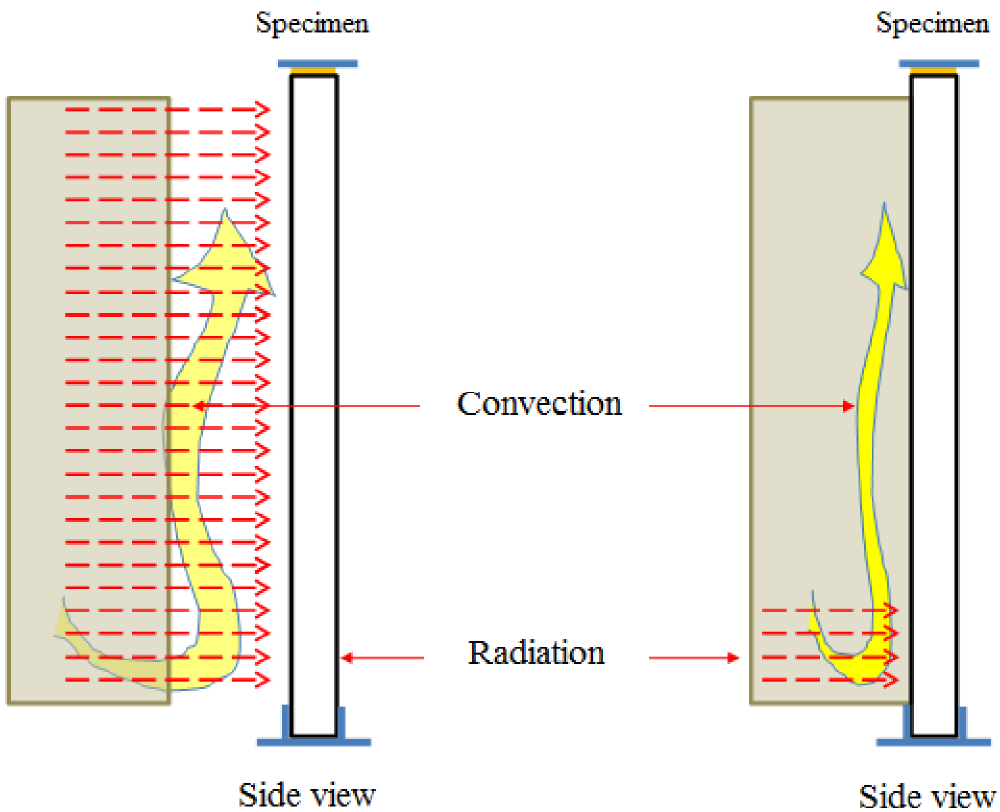

Figure 1. Examples of radiation and convection for heat and thermal shock test in EVSS.

The study observed that depending on the different compositions of the EVSS and the thickness of the specimen, heating and cooling present different behaviors to reach both the surface temperature (80 ± 3 ° C) and the temperature of the thermal shock (25 ± 5 ° C), requiring adjustment of the heat source. The water sprays were standardized by this study to provide a simulation of heavy and constant rain. They had a pressure that did not influence the horizontal displacement of the specimen.

The water used was maintained in a temperature range between 10 to 20° C. The controlled water temperature allowed the sprays to have the same temperature range when reaching the heated surface. These sprays reduced the temperature of specimens to 20 ± 5 ° C.

The reuse of the water during the test was important for water conservation. Each test consisted of 10 heating and cooling cycles, with an estimated consumption of 300 liters of water/cycle/specimen, the vertical system was 1.20 ± 0.20m wide by 2.50m high, totaling consumption of 3,000 liters of water per test. Figure 2 shows the water flow diagram for cooling the specimen, using a booster pump and filter, used to prevent clogging of the water spray nozzles.

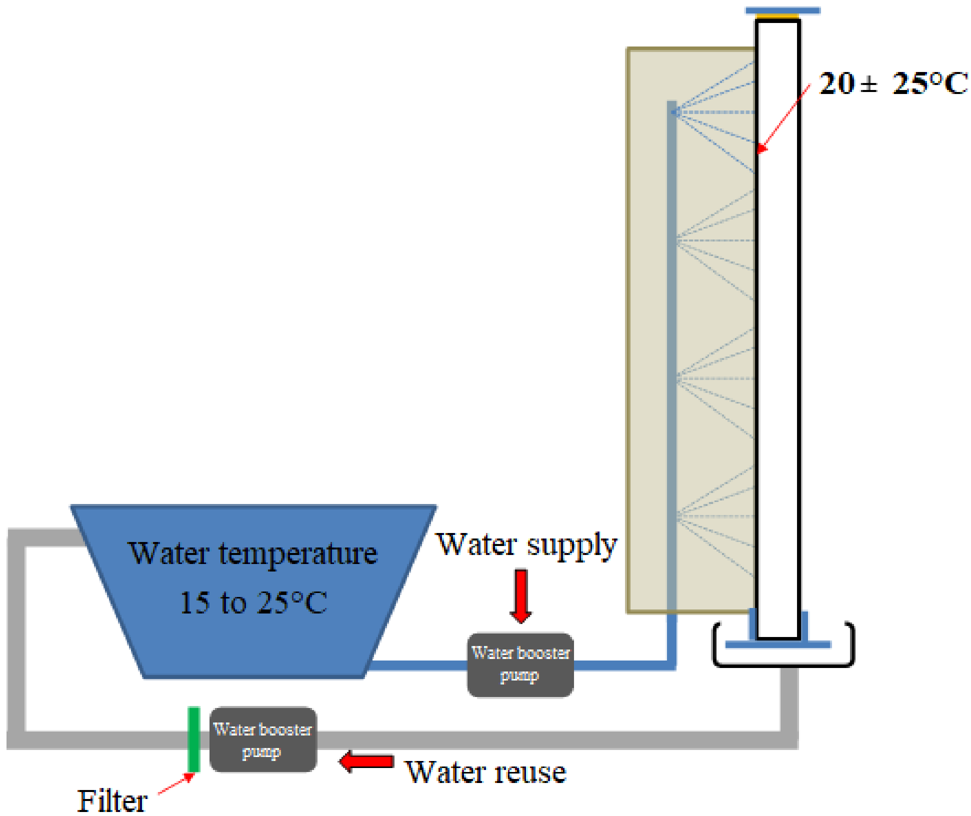

Figure 2. Schematic drawing of water reuse; schematic drawing of the confinement of the specimen with the aid of a support frame and the fixation of the deflectometer support for testing the action of heat and thermal shock in SVVE.

Visual inspection is not always sufficient for an accurate assessment of the degradation suffered by the specimen. All of the rainwater tightness tests happened before and after the heat and thermal shock tests. The second rainwater tightness test was performed again after ten thermal cycles. This test followed the established in NBR 15575-4 (2013).

This study identified the need for adjustments and innovations in the procedure that promote the reproducibility of the exposure conditions, to allow and provide more reliable results with the real behavior in the use of the systems. Table 4 presents new proposals for the heat and thermal shock test.

Table 4. New advances in the heat and thermal shock test.

Testing	New Proposals
Specimen	Restrict the upper part to represent the building system in use
Heating	The heating time between 15 - 20 min for the light and flexible EVSS The heating time between 35 - 40 min for the heavy and rigid EVSS
Water cooling	3min cooling time for light and flexible EVSS 6min cooling time for heavy and rigid EVSS
	Keep the temperature of the water between 10 to 20ºC
Cycles	Apply successive cycles
Radiant panel and water spray equipment	Electrical resistance radiation and ultraviolet lamps

5. CONCLUSIONS

The consolidation of the performance concept, the establishment of clear, objective, and well-defined requirements, and the incorporation of tests to understand the potential performance of systems are examples of a revolution in the construction industry, which directly impacts the design of buildings. Building performance tests are fast, accurate, and reliable means of predicting the potential behavior in the use of EVSS and are relevant for the assessment of building performance. The results obtained by the testing improved the understanding of what to expect as a result of the behavior of construction systems in use, innovative or not, subjected to environmental temperatures and sudden temperature cooling. As expected, the lack of a consolidated history of use and result dissemination prejudices the description of the test procedure and the details of the equipment.
This study did not make any proposal regarding the visual inspection and the number of cycles to which a specimen is subjected when tested, there is a need for criteria, parameters, and limits, to achieve a better assessment and avoid the subjectivity of the visual inspection. About the advances in the method of testing heat action and thermal shock, it was possible to prove that they are relevant and contribute significantly to a better estimate of behavior in the use of EVSS, innovative or not. Thus, the study concluded that the presented proposals have the potential to be incorporated into the procedure of the heat and thermal shock test, promoting a result closer to the real situation.

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