12 – 15 OCTOBER 2021
COIMBRA | PORTUGAL
INTERNATIONAL CONFERENCE
CONSTRUCTION, ENERGY
ENVIRONMENT & SUSTAINABILITY

MOULD GROWTH ON ETICS: THEORETICAL INDICES VS *IN SITU* OBSERVATIONS

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Keywords

ETICS, Hygrothermal behaviour, Moisture, Temperature, Mould growth, Theoretical indices

Abstract

External Thermal Insulation Composite Systems (ETICS) have been frequently used to enhance the thermal insulation of the buildings envelope. However, several questions have been raised on the long-term durability of these systems, namely related to biodeterioration phenomena in which the hygroscopicity of the ETICS is a key factor. In fact, biological growth is often identified on several ETICS façades shortly after their application. This anomaly can lead to cladding defacement, altering the aesthetic appearance of the building.

This paper aims to investigate the influence of the hygrothermal behaviour of four different ETICS on mould growth. The systems tested have different thermal insulation (expanded polystyrene – EPS, expanded cork – ICB, mineral wool – MW), base coat (cement or hydraulic lime-based) and finishing coat (acrylic, silicate, or lime-based). ETICS specimens were exposed for one year at an urban site in Lisbon, Portugal, monitoring the surface temperature (ST) and surface relative humidity (SRH) of the systems for four months (from September 2020 to January 2021). Three theoretical indices, obtained based on ST and SRH results, were used in order to provide an indication on the likelihood of mould growth. Index 1 consists on the percentage of time for which the SRH is equal or higher than 80%. Index 2 represents the percentage of time for which the ST is equal or lower than the dew point temperature of the air. Additionally, index 3 considers the influence of both SRH and ST and represents the percentage of time for which SRH ≥ 80% and 15 ºC ≤ ST ≤ 30 ºC. Furthermore, results were validated by assessing the biocolonization on natural aged ETICS after six months and one-year exposure, using a previously defined scale.

Results showed that ST values were rather constant and with minimal differences among the systems during the night, when higher SRH values were registered. Indices 1 and 3 indicated a higher potential of mould growth for the system with ICB as thermal insulation and finished with a lime-based rendering mortar (S2). No mould growth was detected after one year of outdoor exposure on the system with MW as thermal insulation and acrylic-based finishing coat (S3) as well as on the system with a silicate-based finishing coat (S4). Light mould growth was observed on system S2, and some traces of growth were observed on the acrylic-based system S1. Considering the four months of monitoring in Lisbon, Portugal, the results suggest that indices 1 and 3 can provide an indication on mould growth for the ETICS under study.

1.1 INTRODUCTION

External Thermal Insulation Composite Systems (ETICS) have been frequently used to enhance the thermal insulation of the buildings envelope. These composite systems have several advantages when compared with other thermal insulation solutions, such as the mitigation of thermal bridges, protection of the masonry and structural elements, and reduction of interior water condensation within masonry [1-3]. However, several questions have been raised on the long-term durability of ETICS, namely related to biodeterioration phenomena [3-5]. In fact, biological growth is often identified on several ETICS façades shortly after the building construction and/or rehabilitation. This anomaly can lead to cladding defacement, altering the aesthetic performance of the building, thus compromising a more widespread use of ETICS technology.

Biocolonization on ETICS results from the combined effect of several factors such as surface condensation, wind-driven rain, drying process and rendering properties, being hygroscopicity a key factor [4,6]. Surface condensation occurs whenever the external surface temperature is lower than the dew point temperature of the air. Moreover, if the drying process is slow, a high moisture content may be retained in the substrate for longer periods, increasing the risk of biocolonization, namely by moulds. It is worth noting that the complex biocolonization phenomenon is also influenced by further environmental conditions such as exposure time, soiling, and surface pH.

Several mould prediction models have been developed over the years. However, these models have different simplifications and/or are based on diverse assumptions. Therefore, it is necessary to identify the model limitations by comparing their outcomes with the results obtained from *in situ* observations. As a result, the values of surface temperature and surface relative humidity measured *in situ* are of paramount importance and can be used as input values.

This paper aims to investigate the influence of the hygrothermal behaviour of four different ETICS specimens on mould growth. The tested systems have different thermal insulation materials (expanded polystyrene – EPS, expanded cork – ICB, mineral wool – MW), base coat (with cementitious or hydraulic lime binders) and finishing coat (acrylic, silicate, or lime-based). Systems were exposed for one year at an urban site in Lisbon, Portugal. During outdoor exposure, the surface temperature (ST) and surface relative humidity (SRH) of the systems were monitored for four months. Three theoretical indices were applied using ST and SRH results as input to give an indication on mould growth. At the same time, biocolonization on natural aged ETICS was visually assessed after six months and one-year exposure, using a previously defined scale. Results obtained through the theoretical indices were compared to field tests results (natural aged specimens).

1.2 MATERIALS AND METHODS

Four commercially available and certified ETICS were tested. Table 1 presents the identification and composition of the ETICS considering the information provided by the manufacturers.

Table 1. Identification and composition of the ETICS.

System (S)	Thermal Insulation	Rendering system	
		Base coat*	**Finishing coat**
S1	EPS	Cement, synthetic resins, mineral additives	Acrylic-based, biocide**
S2	ICB	Natural hydraulic lime, cement, mineral fillers, resins and synthetic fibers	Air lime, hydraulic binder, and organic additives
S3	MW	Cement, mineral fillers, resins and synthetic fibers	Acrylic-based, biocide**
S4	ICB	Natural hydraulic lime, mixed binders, and cork aggregates	Silicate-based
*Includes a standard or reinforced glass fiber mesh; **e.g., terbutryn or isothiazole			

Two specimens of each system were exposed outdoors for one year at an urban site in Lisbon, Portugal. The specimens were placed on a rack at 45 degrees of inclination and facing South. The surface temperature (ST) and the surface relative humidity (SRH) of the systems surface were monitored for four months (from September 2020 to January 2021) using monolithic IC devices (Honeywell HIH-4000) and T-type thermocouples. At the same time, biocolonization on the natural aged ETICS was visually assessed using the scale defined in ASTM D5590-17 [7]: 0 – no apparent growth (0% of contaminated surface); 1 – traces of growth (< 10% of contaminated surface); 2 – light growth (10-30% of contaminated surface); 3 – moderate growth (30-60% of contaminated surface; 4 – heavy growth (> 60% of contaminated surface).

Three theoretical indices were applied using ST and SRH results as input to give an indication on the likelihood of mould growth. Index 1 is a simple index commonly used for the indoor assessment of mould growth and also applied by Johansson et al. [7] for building façades and consists on the percentage of time for which the SRH is equal or higher than 80%. On the other hand, index 2 represents the percentage of time for which the ST is equal or lower than the dew point temperature of the air (Tdp). Additionally, index 3 considers the influence of both ST and SRH and represents the percentage of time for which SRH ≥ 80% and 15 ºC ≤ ST ≤ 30 ºC [8] as ideal conditions for mould development.

1.3 RESULTS AND DISCUSSION

A representative period of time for each of the four months of monitoring was selected for the analysis of the results of ST and SRH. Figure 1 shows the surface temperature (ST) and the surface relative humidity (SRH) of the ETICS under study for a representative period of 3 days in November 2020. The highest average ST (27.92 ºC) was obtained for system S3 (MW as thermal insulation, cement-based base coat, and an acrylic-based finishing coat) during the month of September, whereas the lowest average ST (16.97 ºC) was obtained in December for system S2 (ICB as thermal insulation and finished with a lime-based rendering system). During the night, the ST values were rather constant and only small differences can be observed among the systems (Figure 1). On the other hand, the highest SRH (88.56 %) was obtained for system S2 in December and the lowest (57.96 %) was obtained in September 2020 for system S4 (ICB as thermal insulation, hydraulic-lime based base coat, and a silicate-based finishing coat).

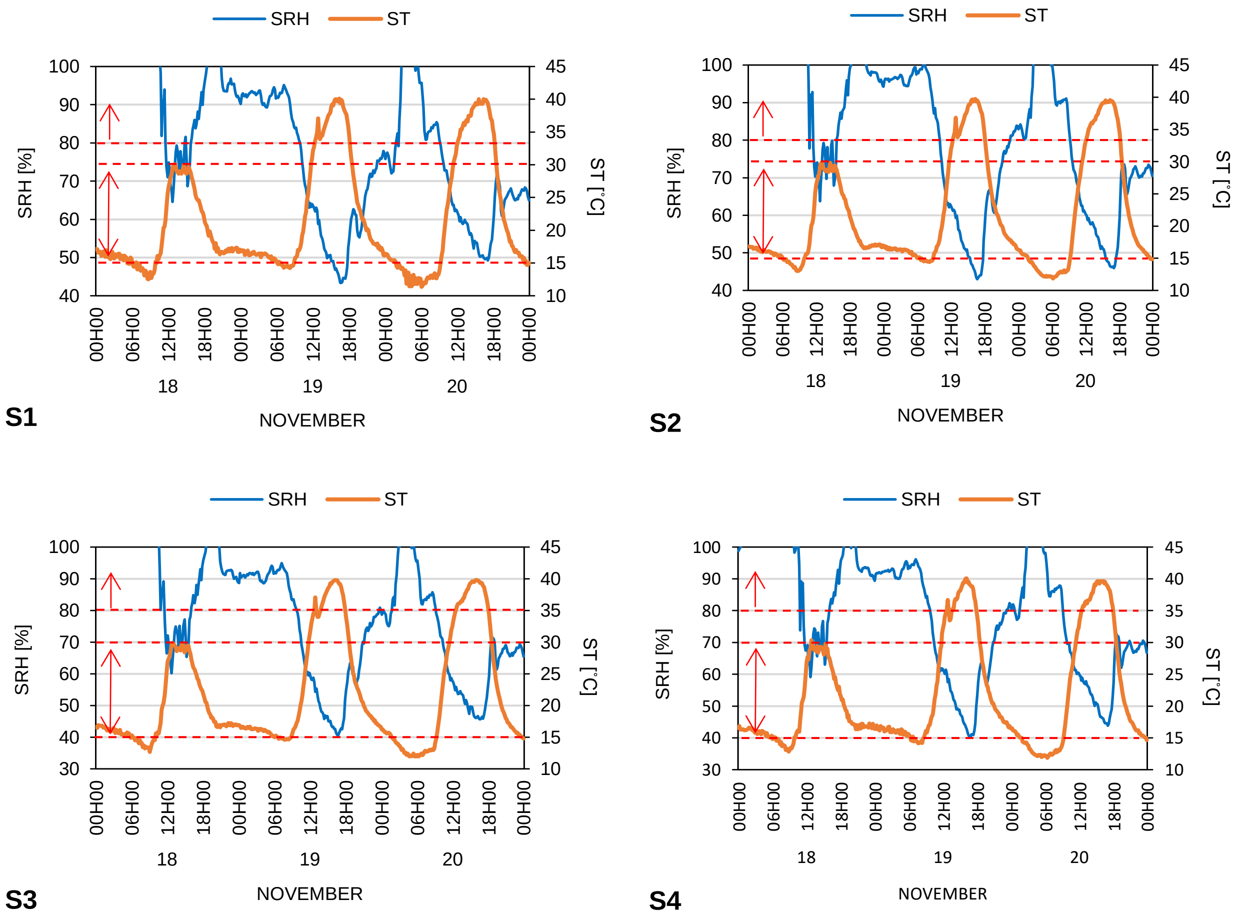

Figure 1. Surface temperature (ST) and surface relative humidity (SRH) for a representative period of November 2020.

When comparing the percentage of time for which the SRH ≥ 80% (Table 2), it can be noticed that higher values of index 1, thus more favourable to mould development, are obtained during December, being the highest results obtained for system S2 (74.54%). However, when considering the average results obtained along the four months, it can be observed that the results of index 1 show minimal differences, ranging between 43.43% for system S4 and 48.93% for system S2 (Table 2) though with large variations within the period studied. The results of index 1 are significantly higher during the night for all systems (Figure 1) when lower results of ST are also obtained. However, index 1 does not consider temperature, thus, it is only meaningful when applied for the study of indoor environments with more constant ST values [8,9].

Table 2. Index 1 – percentage of time for which the surface relative humidity (SRH) is equal or higher than 80% (index 1) (highest monthly values are marked in red and lowest in green).

	Index 1: % of time with SRH ≥ 80%			
	S1	S2	S3	S4
September	17.71	14.58	17.35	14.23
October	51.73	50.35	50.00	49.31
November	51.16	56.25	51.16	53.24
December	55.09	74.54	59.49	56.94
Total (4 months)	43.92	48.93	44.50	43.43

The percentage of time for which the ST is equal or lower than the Tdp (index 2) is presented in Table 3. During the four months of monitoring, the highest percentage of time for which ST ≤ Tdp occurred also in December and for system S1 (EPS as thermal insulation, cement-based base coat, and acrylic-based finishing coat), increasing the risk of surface condensation and therefore the risk of biocolonization [4,10]. When considering the average results of the index 2 of the four systems along the four months of monitoring, lower differences can be observed (results between 4.48% and 5.93%).

Table 3. Index 2 – percentage of time for which the surface temperature (ST) is equal or lower than the dew point temperature of the air (Tdp) (highest monthly values are marked in red and lowest in green).

	Index 2: % of time with ST ≤ Tdp			
	S1	S2	S3	S4
September	0	0	0	0
October	4.52	6.25	3.48	5.21
November	3.24	3.01	3.47	3.47
December	15.97	10.65	10.88	11.11
Total (4 months)	5.93	4.98	4.48	4.95

When considering the index 3 (percentage of time for which SRH ≥ 80% and 15 ºC ≤ ST ≤ 30 ºC) (Table 4), system S2 (ICB as thermal insulation and finished with a lime-based rendering system) obtained the highest results during October, November, and December 2020. The results obtained for the third index are in accordance with those gathered for index 1. However, the results of index 3 are lower than those obtained for index 1.

Table 4. Index 3 - percentage of time for which SRH ≥ 80% and 15 ºC ≤ ST ≤ 30 ºC (highest monthly values are marked in red and lowest in green).

	Index 3: % of time with SRH ≥ 80% and 15 ºC ≤ ST ≤ 30 ºC			
	S1	S2	S3	S4
September	6.94	2.77	5.89	4.17
October	35.77	35.77	35.42	35.06
November	32.88	37.50	32.64	35.65
December	10.18	14.82	10.65	8.79
Total (4 months)	21.44	22.72	21.15	20.92

Table 5 shows the results of the average rate of mould growth on systems after six months and one year of outdoor exposure. The results of the average rate show no biological growth in systems S3 (MW as thermal insulation, cement-based base coat, and an acrylic-based finishing coat) and S4 (ICB as thermal insulation, hydraulic lime-based base coat, and a silicate-based finishing coat). These results can be explained by the presence of biocide on the finishing coat or by the high levels of pH of the finishing coats of the systems [1]. On the other hand, light mould growth was observed on system S2 (ICB as thermal insulation and finished with a lime-based rendering system) and some traces of growth were also observed on system S1 (EPS as thermal insulation, cement-based base coat, and acrylic-based finishing coat).

Table 5. Average rate of mould growth on aged systems.

	S1	S2	S3	S4
6 months	0	0.5	0	0
1 year	0.5	1.5	0	0

When comparing the results presented in Table 5 with those obtained from the indices, it can be observed that both index 1 and index 3 can be used to give an indication on mould growth considering the four months of monitoring: the system S2 with the highest mould development rate (Figure 2a) obtained also the highest values of index 1 and 3. However, index 1 only assumes the SRH and it may result in a more conservative approach, especially during the night, when the values of SRH are too high and the values of ST too low. Previous studies (e.g., [6]) show that mould growth can be limited for low values of temperature. The third index considers both ST and SRH and thus can be more reliable for the prediction of mould growth.

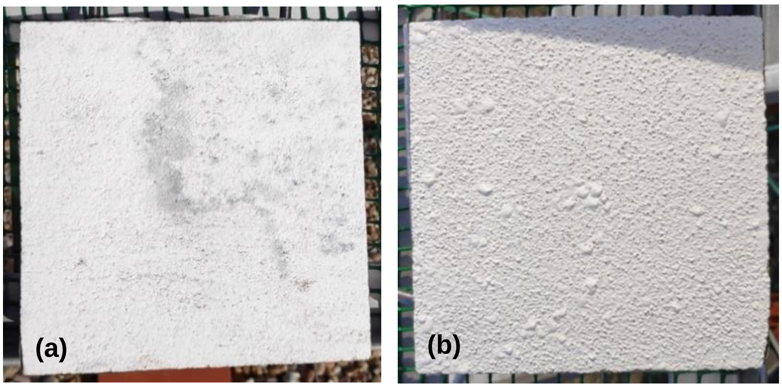

Figure 2. Biological growth observed on system S2 after one-year of outdoor exposure (a) and surface condensation on the acrylic-based system S1 (b).

1.4 CONCLUSIONS

To study the influence of the hygrothermal behaviour of four different ETICS on mould growth, ETICS systems were exposed outdoor for one-year at an urban site in Lisbon (Portugal), monitoring the surface temperature and the surface relative humidity of the systems for four months. Surface relative humidity and temperature were used as input data for three theoretical indices, which can provide an indication on potential mould growth. Biological colonization was also visually assessed after six months and one-year exposure, using a previously defined scale. The results obtained through the theoretical indices were compared to the results from field tests. The main conclusions can be resumed as follows:

- System S3 with a mineral wool thermal insulation and an acrylic-based finishing coat showed the highest average surface temperature (27.92 ºC) during the warmer month of September. On the other hand, the lowest average surface temperature (16.97 ºC) was presented, in the monitored coldest month (December), by the system with ICB as thermal insulation and finished with a lime-based rendering mortar (S2). During the night, the surface temperature values were quite constant and minimal differences can be observed among the systems.

- The highest average surface relative humidity (88.56%) was obtained for system S2 during December, whereas the lowest (57.96%) was obtained in September for the system with ICB as thermal insulation and a silicate-based finishing coat (S4). The highest values of surface relative humidity were registered during the night.
- The index 1 indicated a higher potential of mould growth for system S2. However, this index neglects the effect of the temperature and can therefore lead to unreliable results. In fact, index 1 is only meaningful when applied for the study of indoor environments with more constant ST values.
- The index 2 indicated a higher potential of mould growth for the acrylic-based system S1. However, minimal differences were obtained among the systems.
- The index 3 indicated a higher potential of mould growth for system S2. The results obtained for index 3 are in accordance with those gathered for index 1. However, the results of index 3 are lower (less conservative) than those obtained for index 1.
- No mould growth was detected after one year of outdoor exposure for systems S3 and S4. Light mould growth (10 to 30% of contaminated surface) was observed on system S2 and some traces of growth (< 10% of contaminated surface) were observed on the acrylic-based system S1. The results of the present study suggest that indices 1 and 3 are in agreement with field tests and thus can provide an indication on mould growth for the analysed ETICS systems under Mediterranean climate conditions. It is worth noting, however, that the results of the indices were obtained considering four months of monitoring and the climatic conditions of Lisbon during those months. Future research should consider longer monitoring periods as well as different environmental conditions.

Acknowledgements

Authors acknowledge the support given by the Portuguese Foundation for Science and Technology (FCT) for the research project WGB_Shield (PTDC/ECI-EGC/30681/2017) and the Ph.D. scholarships 2020.05180.BD and PD/BD/127848/2016 of J. Parracha and J. Pereira, respectively. Authors also acknowledge CERIS research centre (IST, Lisbon) for funding the seed project Bi-THEM (UIDB/04625/2020).

References

[1] Parracha, J.L.; Borsoi, G.; Flores-Colen, I.; Veiga, R.; Nunes, L.; Dionísio, A.; Gomes, M.G.; Faria, P., 2021. "Performance parameters of ETICS: Correlating water resistance, bio-susceptibility and surface properties", Construction and Building Materials 272, 121956.

[2] Parracha, J.L.; Borsoi, G.; Veiga, R.; Flores-Colen, I.; Nunes, L.; Garcia, A.R.; Ilharco, L.M.; Dionísio, A.; Faria, P., 2021. "Effects of hygrothermal, UV and SO_2 accelerated ageing on the durability of ETICS in urban environments", Building and Environment 108151.

[3] Amaro, B.; Saraiva, D.; de Brito, J.; Flores-Colen, I., 2013. "Inspection and diagnosis system of ETICS on walls", Construction and Building Materials 47, 1257-1267.

[4] Barreira, E.; de Freitas, V.P., 2013. "Experimental study of the hygrothermal behaviour of External Thermal Insulation Composite Systems (ETICS)", Building and Environment 63, 31-39.

[5] D'Orazio, M.; Cursio, G.; Graziani, L.; Aquilanti, L.; Osimani, A.; Clementi, F.; Yéprémian, C.; Lariccia, V.; Amoroso, S., 2014. "Effects of water absorption and surface roughness on the bioreceptivity of ETICS compared to clay bricks", Building and Environment 77, 20-28.

[6] Johansson, P.; Ekstrand-Tobin, A.; Svensson, T.; Bok, G., 2012. "Laboratory study to determine the critical moisture level for mould growth on building materials", International Biodeterioration & Biodegradation 73, 23-32.

[7] ASTM D5590-17:2017. "Determining the resistance of paint films and related coatings to fungal defacement by accelerated four-week agar plate assay", ASTM International, Pennsylvania, USA.

[8] Johansson, S.; Wadsö, L.; Sandin, K., 2010. "Estimation of mould growth levels on rendered façades based on surface relative humidity and surface temperature measurements", Building and Environment 45, 1153-1160.

[9] Vereecken, E.; Roels, S., 2012. "Review of mould prediction models and their influence on mould risk evaluation", Building and Environment 51, 296-310.

[10] Hagentoft, C-E., 2001. "Introduction to Building Physics", Studentlitteratur, Sweden.