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Suitability of Some Existing Damage Indexes for Assessing Agreements in Maintenance and Management of Museum Climatization Systems

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ABSTRACT

Heating, Ventilating and Air-Conditioning systems in museums are called to properly control important microclimate parameters, not only for visitors' wellbeing, but mostly for the preservation of works of art. Accordingly, in case of interruptions to Heating, Ventilating and Air-Conditioning systems, due to maintenance interventions or drawbacks, it is essential to guarantee the acceptable break from service to which possible damages for the works of art are related. In this regard, the aim of this work is to introduce a simple indicator to support curators in regulating the stipulation of contracts with external companies, a more effective management and maintenance of the Heating, Ventilating and Air-Conditioning systems will thus be achieved in order to preserve the works of art, by integrating into the contracts economic penalties related to the system's service break period. The feasibility of this new procedure has been checked by means of a case study involving the "Museo Regionale" of Palermo (Italy).

KEYWORDS

Works of art preservation, Risk indexes, Environmental conditions, Museums, Heating, ventilating and air-conditioning management and maintenance service contract, Economic cost.

INTRODUCTION

The proper control of indoor microclimate conditions in museums represents a crucial situation for guaranteeing the correct preservation of the exhibited works of art [1, 2],

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especially when museums are hosted by historical buildings [3, 4], being cultural heritage items themselves. Such conditions are often achieved by means of Heating, Ventilating and Air-Conditioning (HVAC) systems that, essentially, operate on the thermodynamic properties of the indoor air of the museum's rooms [5, 6]. Nowadays a wide debate is open among the operators about the features that new technological systems must have in order to be installed in museums, also involving the role of the so-called Best Available Technologies [7, 8]. However, several museums are still equipped with old and/or improperly sized HVAC systems [9]. This causes that these systems, apart from their significant energy use [10], are often subjected to interruptions for maintenance operations or, accidentally, for undesired failures. These eventualities introduce an undesired delay of the planned breaks, likely resulting in unsuitable microclimate conditions for the works of art. On the other hand, such drawbacks could determine unsuitable indoor microclimate conditions with possible discomfort for the museum visitors and workers.

It must be noted that these requirements can be controversial, since the environmental conditions required for preserving the works of art sometimes are not able to guarantee comfort of people at the same time [11, 12], sometimes they might also conflict with the requisites of energy efficiency [13, 14]. Also, different works of art generally require different environmental conditions for their proper preservation [15, 16]. Furthermore, a study reported in La Gennusa *et al*. [17] showed how, when buildings like museums and galleries are involved, the methods to be used for assessing the indoor air quality, should not be too invasive in order not to interfere with the exhibition scene.

An Italian standard [18], which defines proper physical indoor parameters for items exhibited in galleries and museums, asserts that curators are in charge of the final decision about the environmental conditions of each item, since the most suitable microclimatic conditions strongly depend on the environmental history of the item itself, and this latter is usually well known only to the curator. Curators and/or people responsible for the general running of museums are indeed the ones called to assess effective strategies in order of limiting an excessive interruption of the HVAC service. For this purpose, they must pay the highest attention to properly draw up the contracts that regulate the relationships with the companies in charge of the design, maintenance and repairing services of the museum's HVAC system [19, 20]. In fact, among other things, the contractors "… pay the bill when they fail to respond to an emergency within the agreed-on time period …" [21].

According to the above-cited considerations, the evaluation of the quality of microclimate conditions of museums consists not only in verifying that the environmental parameters fall within the tolerance intervals for the preservation of works of art, but also in taking into account the probability of occurrence of the HVAC systems' malfunctioning (time during which such parameters fall outside the optimal range).

The present work, after a short review of some available indexes of risk for the preservation of works of art, introduces a new simple indicator (the *EI* indicator) intended as a support for curators to properly evaluate the planned interruptions for maintenance operations of the HVAC systems and to establish the maximum time of acceptable discontinuity in service. This indicator can also be utilized for defining appropriate penalties to be paid by the companies in case of overruns of the interruption periods [22-24].

The feasibility of the proposed new indicator has been verified in the "Museo Regionale" of Palermo (Italy), two halls of which – previously subjected to measurements of indoor parameters – have been considered to provide an example of the *EI* indicator's calculation.

EXISTING SYNTHETIC INDEXES

Since the relevance of risks related to the HVAC systems' discontinuity period is associated with their maintenance and management effectiveness, some literature indexes attempting to estimate the probable risk of damage in connection with assigned environmental conditions associated to pre-set reference values, are described in the following sections [25]. The aim of this preliminary analysis is to verify whether some of these existing indicators can be utilized for supporting curators in their relationships with HVAC systems' providers.

Performance Index

The Performance Index (*PI*) is defined as the percentage of time during which a measured parameter lies within the recommended/required tolerance interval [26-28]. Its most important feature is the definition of microclimate "warning limits" (such as air temperature and relative humidity) not to be exceeded, whose set up should be assessed according to the curators' experience.

PI is mainly used to verify whether a museum HVAC system is suitably designed to maintain the microclimatic conditions, which are required for the preservation of exhibited works of art, within the limits suggested by the reference Italian standard [18] and the Italian Ministerial Degree [28, 29]. In more detail, *PI* is defined as the percentage of hours, for each month of the considered year, in which the values of air temperature (*T*) and Relative Humidity (*RH*) fall inside the ranges recommended by the Italian standard UNI 10829 [18] or the Italian Ministerial Degree of 10th May 2001 [28].

For example, for paintings on wood the cited Standard recommends for indoor air a range of values between 19 °C and 24 °C for the temperature and between 50% and 60% for the relative humidity, for frescoes, on the other hand, the suggested limits are comprised between 10 °C and 24 °C and 55% and 65% for the air temperature and its relative humidity, respectively.

Time Weighted Preservation Index

The "Preservation Index", proposed by the Image Permanence Institute (IPI) [30], is based on a detailed study of the hydrolysis cellulose acetate reaction and has been proposed as gauge of the combined effects of air temperature and relative humidity of the storage/exhibition environments on organically composed works of art.

This preservation index (expressed in years) is related to the kinetics of the reaction and is based on the period of time (*lifetime*) for the works of art to remain in good condition referring to the quality of the microclimate to which they are exposed, as reported in eq. (1):

$$lifetime = \frac{e^{\frac{95{,}220 - 134.9 \times RH}{8.314 \times T} + 0.0284 \times RH - 28.023}}{365} \quad (1)$$

where *T* [K] and *RH* [%] are the detected values of air temperature and relative humidity of the given environment, respectively.

To consider the overall impact of the changes in air temperature and relative humidity on the organic materials' rate of chemical degradation over time, the Image Permanence Institute also introduced the Time Weighted Preservation Index (*TWPI*) which may be calculated using eq. (2):

$$TWPI_n = \frac{n \times TWPI_{n-1} \times lifetime_n}{lifetime_n \times (n-1) + TWPI_{n-1}} \quad (2)$$

where n is the total number of considered time intervals, $TWPI_{n-1}$ is the value of *TWPI* at the $(n-1)$-th time interval, and $lifetime_n$ is the value of the *lifetime* parameter calculated at the time interval n.

Kinetic Theory Approach Index

A useful mathematical model to describe the degradation of works of art due to the action of external agents has been introduced by Brazzoli *et al*. [31]. This model, based on the Kinetic Theory Approach [32], assumes that the state of a given system can be identified by a number of independent variables, each one linked to a proper probability distribution. Based on this assumption, the action exerted by the environment surrounding the works of art can be decomposed into a suitable number of random variables, therefore, a stochastic description is needed to consider the random fluctuations related to the state variables of the system. Furthermore, this model takes into account the effects of the external actions on the artefact and the internal interactions among the artefact's components. For the sake of simplicity, it can be assumed here that the considered artefact are composed by a single type of material.

Specifically, the kinetic theory is based on a statistical evaluation [31] of the two limit conditions for the considered system, that is, in this case, the conditions of total degradation and of optimal conservation of the work of art. On purpose, the utilized stochastic approach considers a functional index, here named *KT*, with its limit values: $KT = 0$ (total degradation) and $KT = 1$ (optimal conservation), the intermediate points between these limits depend on the values assumed by the considered variables, air temperature and relative humidity, for each analysed artefact.

PROPOSAL OF A NEW INDICATOR OF DAMAGE RISK FOR WORKS OF ART

The indexes reported in the previous section, although very useful for the specific purpose for which they have been implemented, do not completely meet the scope of the present work, which is singling out an operational parameter that curators could usefully apply when approaching the assessment of suitable contracts concerning the maintenance and management of HVAC systems in exhibition halls.

In fact, the *TWPI* index takes into account only the chemical degradation of organic materials, mainly referring to the changes in the air temperature values, and it does not suitably consider other types of damage. On the other hand, the indicator based on the kinetic theory depends on coefficients whose fixed values are not always well known. As for the *PI*(*T*) and *PI*(*RH*) indexes, due to their inherent definition, they consider the two environmental physical parameters singularly, in this way not considering the damage induced by the contemporary effect of air temperature and relative humidity whose synergic contribution is of paramount relevance in establishing the environmental related risk to works of art. In addition, despite the fact that the *PI*(*T-RH*) index would be theoretically eligible for the purpose of this work, it does not consider the distance between the actual environmental conditions and the suggested maximum and minimum limits values of air temperature and relative humidity set by the current regulations.

On the ground of the above reported considerations, in this section a new approach is proposed in order to allow curators to evaluate the reliability of the companies responsible for the maintenance and management of HVAC systems, based on the damage risk assessment related to the works of art exhibited in museums. This approach tries to take into account not only the percentage of time during which the physical parameters characterizing a given environment fall outside the suggested optimal range, but also the gap between such parameters and their relative safety ranges over a considered period of time. This will allow to single out the situations in which artefacts are more likely exposed to risk conditions in case of a HVAC system failure.

Noticeably, a relevant feature of such indicator should be its capability of properly taking into account the knowledge of the curators concerning the history of the considered works of art.

New indicators of damage risk: The Integrated Over Range and Integrated Under Range indexes

The proposed approach initially requires an analysis of the environmental conditions of the considered storage/exhibition halls when the climatization system is not in operation. In other words, a monitoring campaign of the two involved exhibition halls (hosting the Virgin Annunciate and the Triumph of Death, respectively) in free-floating conditions has been performed. This is important in order of establishing the ex-ante behaviour of the indoor physical parameters (air temperature and relative humidity, in this case).

The proposed approach is based on the evaluation of doses of air temperature (*T*) and/or Relative Humidity (*RH*) on the microclimatic environment surrounding the under study work of art rebuilt considering a response time constant of three days [33]. In this aim, two indexes for each microclimatic parameter are here introduced (Figure 1):

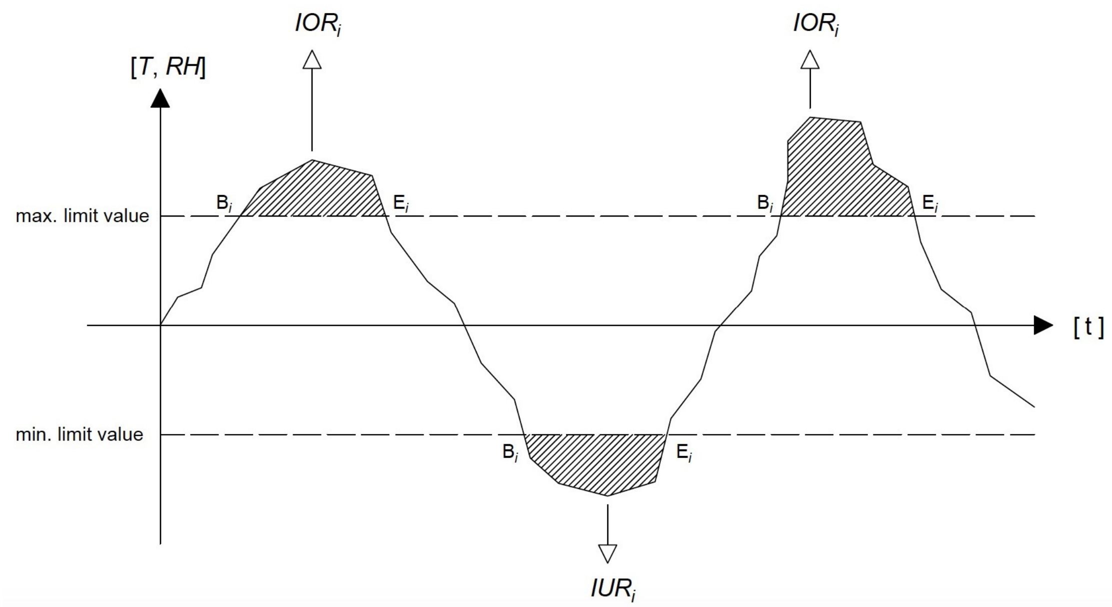

Figure 1. Graphical representation of the *IOR* and *IUR* indicators

- The Integrated Over Range (*IOR*) index, which is the integration over time of positive differences between the monitored values and the upper limits of the optimal range:

$$IOR_T = \sum_{i=1}^{Os} \int_{B_i}^{E_i} \Delta T \times dt \tag{3}$$

$$IOR_{RH} = \sum_{i=1}^{Os} \int_{B_i}^{E_i} \Delta RH \times dt \tag{4}$$

- The Integrated Under Range (*IUR*) that is the integration over time of negative differences between the monitored values and the lower limits of the optimal range:

$$IUR_T = \sum_{i=1}^{Us} \int_{B_i}^{E_i} \Delta T \times dt \tag{5}$$

$$IUR_{RH} = \sum_{i=1}^{Us} \int_{B_i}^{E_i} \Delta RH \times dt \tag{6}$$

where *Os* represents the number of exceedances above the considered optimal range, Us represents the number of exceedances below the considered optimal range, B_i represents the initial instant of time of the i-th exceedance and E_i represents the final instant of time of the i-th exceedance.

The considered response time constant takes into account how the work of art reacts to the modality of variation of the microclimatic parameters. In fact, a high distance from the optimal ranges of air temperature and relative humidity confined in a short period of time would imply different effects compared to a smaller distance from the optimal ranges but prolonged over a longer period of time.

Therefore, the microclimatic quality of the environment with respect to the safety of the exhibited works of art is simply defined by means of two indicators for each parameter, respectively, referred to air temperature and relative humidity. Hence, a total of four indicators are required to define the quality of the environmental conditions in relation to an eventual malfunctioning of the HVAC system.

An Economy Related Impact Indicator

On the basis of their definitions, *IOR* and *IUR* could be directly utilized for evaluating the periods of time during which a given work of art is exposed to potentially dangerous microclimatic conditions. In addition, it has been hypothesized that they can also be utilized for building up a new integrated indicator, the Economy Related Impact Indicator (*EI*), to help curators of museums and exhibition halls in suitably compiling contracts with the companies that are in charge of the management of HVAC systems.

Clearly, with this scope in mind, the economic aspects must also be taken into consideration. For this purpose, the previously defined *IOR* and *IUR* indicators are here utilized for the economic evaluation related to non-working periods of the HVAC system. Indeed, these indicators could be helpfully blended by means of proper weighting factors, in order of leading up to an integrated formulation of the risk related to a poor maintenance or a malfunctioning of the HVAC system. That is:

$$EI = (\alpha^{+} \times IOR + \alpha^{-} \times IUR)_{T} + (\beta^{+} \times IOR + \beta^{-} \times IUR)_{RH} \tag{7}$$

where *IOR* and *IUR* are the values obtained by means of the application of eqs. (3-6), α and β are suitable weights, respectively, referred to air temperature and relative humidity, representing the impacts that the changes in these microclimatic parameters, from the suggested optimal ranges, would have on the works of art. Such weighting coefficients should assume different values depending on the suggested microclimatic ranges for the preservation of the work of art and on the materials constituting the artefact. Moreover, the "exhibition history" of the work of art should be properly considered by referring to the experience of curators.

Tentatively, the use of a continuous scale of values for α and β, comprised between 0 (minimum impact) and 1 (maximum impact), is proposed in Table 1.

These values, for the sake of simplicity, represent a first tentative proposal, based on the optimal ranges suggested by the Italian technical standard UNI 10829 [18]. Of course, their final assessment should be agreed with curators.

Apart from the definition of the above-mentioned weighting parameters, the structure of the algorithm reported in eq. (7) is characterized by some relevant simplifications, the most important of which is represented by the implicit assumption of a linearity law (that is a summation) of the effects determined by air temperature and relative humidity.

Table 1. Tentatively proposed scale of values for the weighting coefficients α and β

α		β	
Temperature* (ΔT) [°C]	Weighting coefficient value	Relative humidity* (ΔRH) [%]	Weighting coefficient value
$\Delta T \leq 4$	1	$\Delta RH \leq 10$	1
4 °C < $\Delta T \leq$ 6 °C	0.8	10% < $\Delta RH \leq$ 20%	0.8
6 °C < $\Delta T \leq$ 8 °C	0.6	20% < $\Delta RH \leq$ 30%	0.6
8 °C < $\Delta T \leq$ 10 °C	0.4	30% < $\Delta RH \leq$ 40%	0.4
10 < ΔT	0.2	40 < ΔRH	0.2

* Suggested ranges of values based on the Italian technical standard UNI 10829 (1999) [18]

APPLICATION TO A CASE STUDY

As previously mentioned, the feasibility of the proposed approach has been verified in the "Museo Regionale" of Palermo (Italy), two halls of which have been considered to provide an example application of the *EI* indicator's calculation. As already reported, the indoor air physical parameters of these two rooms have been preliminary measured in free-floating conditions.

Description of "Palazzo Abatellis" museum

The museum is hosted by Palazzo Abatellis (Figure 2), a palace located in the historic centre of the city, along Via Alloro, which is the main artery of the Kalsa ancient district that, at the end of the 15th century, by virtue of its proximity to the port, recorded its maximum urban development.

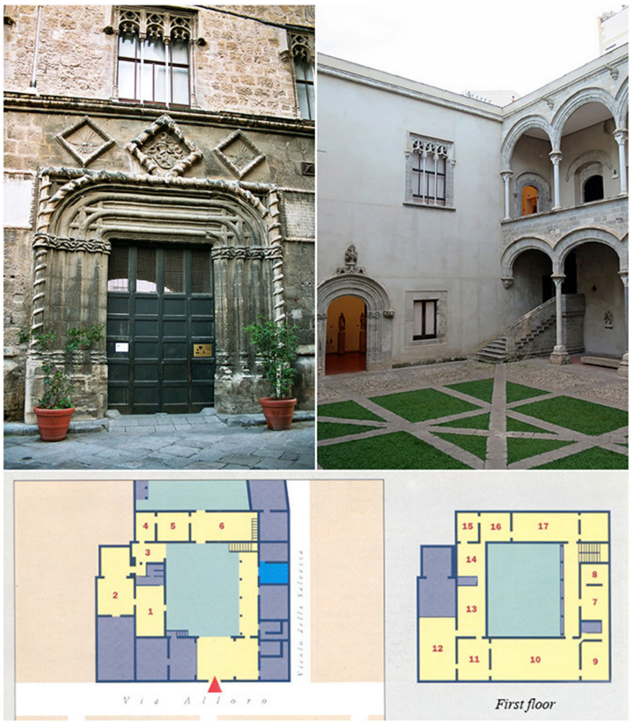

Figure 2. Palazzo Abatellis entrance (top left), internal atrium (top right) and exhibition halls' layout (bottom left and right) (source: "Archivio fotografico di Palazzo Abatellis", http://www.celeste-ots.it/musei_siciliani/museo10_1.htm)

The museum was built in the late 15th century by Matteo Carnalivari as the residence of Francesco Abatellis, port master of the Kingdom of Sicily, and it is one of the most significant buildings of Gothic-Catalan architecture in western Sicily. The building was later used as a monastery and underwent many transformations over time. Severely damaged by the bombings of 1943, the building was lately restored by the Superintendence of Palermo. In 1953-54, with the museum set up by Carlo Scarpa, it became the headquarter of the National (now Regional) Gallery of Sicily. This Gallery reports the evolution of the figurative culture in Palermo, and in western Sicily, from the 12th to the 18th century. The Gallery's collections come from acquisitions, donations and confiscation of assets of suppressed religious bodies. Before joining the current site, these goods were part of the Picture Gallery of the Royal University and then, starting from 1866, the collections of the National Museum of Palermo.

The works of art (Figure 3) considered in this case study are described in the following:

- The Triumph of Death (exhibition hall #2), a fresco considered as one of the most representative works of the late Gothic painting in Italy. The author of the work, which dates back to 1446, is unknown;
- The Virgin Annunciate (exhibition hall #10), a painting by the Italian Renaissance by Antonello da Messina, probably painted in Sicily in 1476, shows the Virgin interrupted at her reading by the Angel of the Annunciation.

According to the Italian standard UNI 10829 [18] and the Italian Ministerial Degree of 10 May 2001 [28], the recommended ranges of air temperature *T* and relative humidity *RH* for these works of art are: *T* comprised between 19 °C and 24 °C and *RH* comprised between 50% and 60% for the Virgin Annunciate, while *T* comprised between 10 °C and 24 °C and *RH* comprised between 55% and 65% for the Triumph of Death.

Figure 3. The Triumph of Death on the left and the Virgin Annunciate on the right (source: "Archivio fotografico di Palazzo Abatellis", http://www.regione.sicilia/beniculturali)

The monitoring of the two considered microclimatic parameters (air temperature and relative humidity), in free-floating conditions, inside the halls hosting the two works of art has been performed for a whole year (2011), as reported in Figure 4.

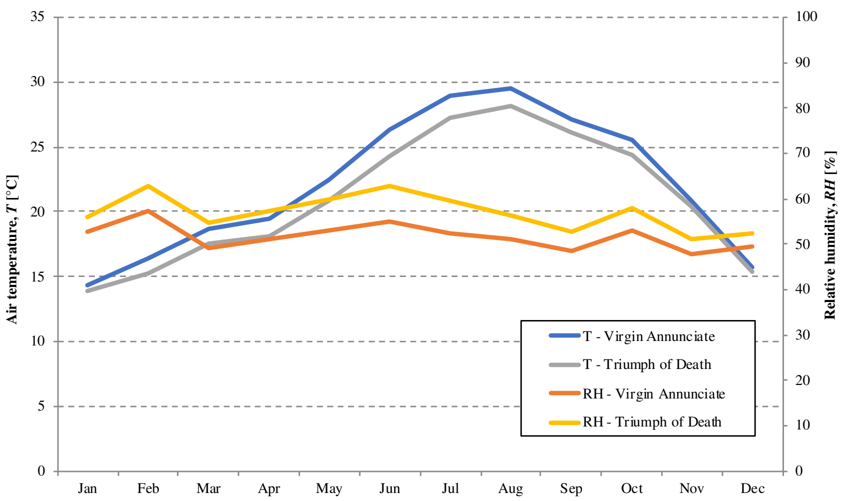

Figure 4. Yearly trend of the monitored values of air temperature (*T*) and relative humidity (*RH*) in the exhibition halls hosting the two considered works of art

Simulations

Since this work aims at singling out an operative integrated indicator for helping museums' curators when stipulating contracts with HVAC maintenance and management companies, a simulation procedure has been implemented in order of comparing the new *EI* indicator here introduced with other existing indexes (see Section 2) showing some potentialities for assessing the microclimate-related risk for the works of art.

To run the simulations, it has been hypothesized to install an ideal air conditioning system inside Palazzo Abatellis, able to maintain at established constant values the indoor air temperature and relative humidity. In particular, for the indoor air temperature a value of 21 °C has been set for both the exhibition rooms hosting the two works of art, while the values of relative humidity in the two rooms have been set equal to the average of the limit values suggested by the technical standard for this kind of artwork exhibited, that is 55% for the Virgin Annunciate and 60% for the Triumph of Death.

The mathematical simulation procedure to calculate the existing indexes *PI*(*T*-*RH*), *TWPI*, *KT* and the new indicator *EI*, according to the pertinent equations reported in Section 2 and Section 3, has been implemented by means of the MATLAB™ environment. Specifically, different periods of interruptions of the air conditioning system were simulated, during which the above-mentioned pre-set (fixed) values of air temperature and relative humidity were substituted with the corresponding monitored (time-dependent) values of the same physical parameters. The simulations were initially carried out considering a period of interruption of the HVAC system equal to 15 consecutive days: a total number of 8,760 interruption periods were simulated, starting from the first hour of the first day of the year and postponing the service interruption of one hour each time. Subsequently, the same simulations were performed considering, instead, a period of interruption of 5 days.

RESULTS AND DISCUSSION

The results of the simulations have been analysed using a monthly statistical analysis. In order to compare the existing indexes with the new proposed indicator, the results obtained from the performed simulations were normalized by using a scale of values comprised between 0 and 1, where 1 represents a critical microclimatic condition for the work of art, and 0 corresponds to an acceptable condition. Specifically, the statistical analyses lead to some consideration reported in the following.

Concerning the *PI*(*T*-*RH*) index for the Virgin Annunciate as well as for the Triumph of Death, in both cases of the hypothesized service interruption period it gave on average higher values respect to the others indexes. Moreover, the *PI* (*T*-*RH*) presented a wider change as regards both the symmetry of the distribution and the dispersion of the values. A slight difference concerning the most critical periods was found between the two works of art, which turned out to be June-September and December-January for the Virgin Annunciate and July-September for the Triumph of Death, regardless of the duration of the HVAC interruption period.

With reference to the results of the *KT* index, the influence of the different interruption periods emerged in both the symmetry and the dispersion of values with regard to the Virgin Annunciate, for which the most critical months resulted to be April, May, October and November. Relatively to the Triumph of Death, instead, *KT* presented an almost identical trend for the two considered interruption periods, with higher values in the interval June-October.

In order to better emphasize the advantages introduced by the new proposed indicator *EI*, it was decided to report in the following Figure 5 a comparison between the monthly median values of the *EI* indicator and the *TWPI* index, as this latter, among the existing indexes, represents the one theoretically more suitable for the purpose of this work.

Looking at the *TWPI* results reported in Figure 5, it can be observed how the graphs regarding the Virgin Annunciate show a very similar trend for both interruption periods, hence the *TWPI* does not seem to be particularly influenced by the change in the period of interruption, the critical period goes from June to October. This index, however, does not give useful information for the Triumph of Death.

In Figure 5 the behaviour of the new *EI* indicator is also reported. As it is evident, relatively to the Virgin Annunciate, *EI* appears to be strongly influenced by the season change and by the variation of the interruption interval. In fact, going from 5 to 15 days of interruption of the HVAC system, an increase in the values of the indicator can be observed. The fact that a similar behaviour is not equally evident in the graphs relative to the Triumph of Death may be due to two main reasons:

- The recommended range of air temperature *T* for frescos (10-24 °C) is wider than that suggested for paintings on wood (19-24 °C);
- The different exhibiting choices for the two works of art, since the Virgin Annunciate is contained in a showcase located at the centre of exhibition hall #10, while the Triumph of Death is put against a wall in exhibition hall #2. Despite this, the *EI* indicator seems to give more useful information than the *TWPI*, which shows an almost flattened trend.

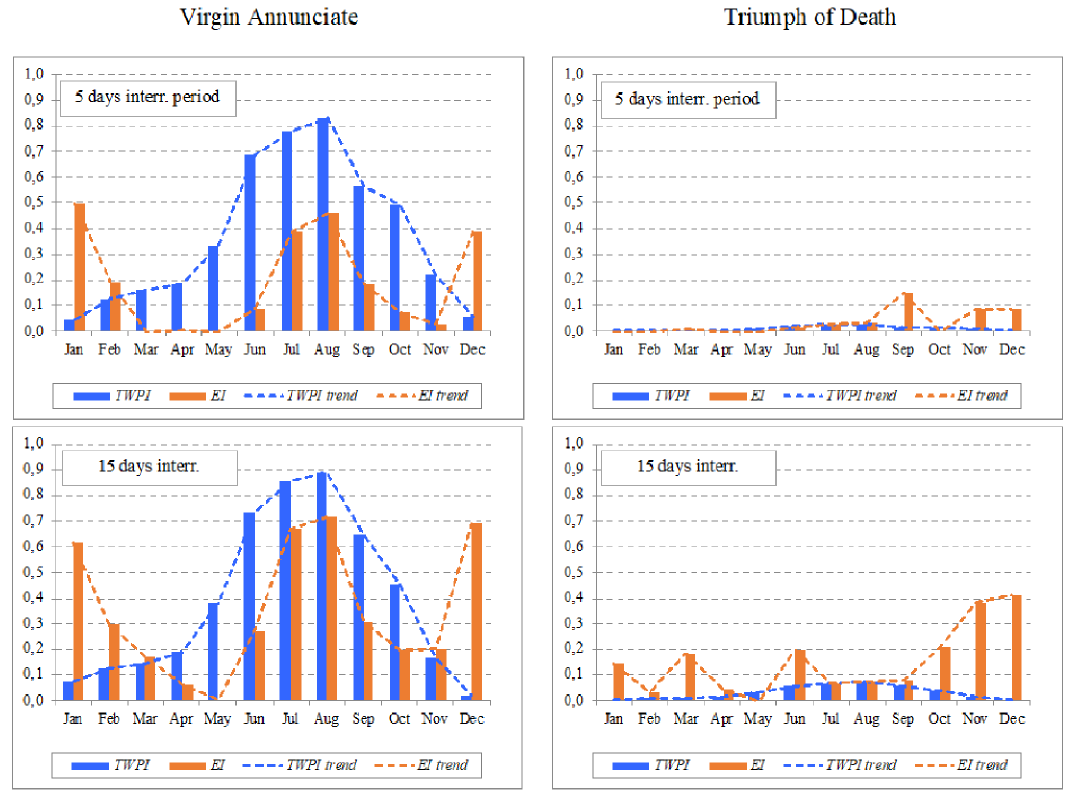

Figure 5. Comparison between the *EI* indicator and *TWPI* index relative to the considered works of art, for the two hypothesized HVAC system interruption periods

The observed differences among the existing indexes and the new proposed indicator (and the hypothesized periods of interruption) are ascribable to their intrinsic definitions. In fact, *PI*(*T-RH*) does not consider the distance between the monitored values of air temperature and relative humidity and their relative suggested limits. The index *KT*, instead (although showing the best intrinsic structure, able to consider several effects induced by the microclimate on the specific materials constituting the examined work of art), depends on fixed (not present in the scientific literature) coefficients that are based on the different typologies of works of art. The *TWPI*, finally, is only suited for works of art composed of organic materials, besides, it shows a strong dependence on the air temperature and, conversely, a weak dependence on the relative humidity. On the contrary, the new indicator *EI* is built-up to effectively evaluate the distance of the monitored values of air temperature and relative humidity from the corresponding allowed relative ranges, and it also takes into account the response of each specific work of art by means of the considered "response time constant".

This feature candidates the *EI* indicator as a suitable one for evaluating the shortest conceivable period of HVAC malfunctioning to which possible damages to the works of art are related. Therefore, *EI* could be adopted as a decision support for curators in regulating their contracts with the companies providing the service of maintenance and management for HVAC systems (i.e. evaluating the planned interruptions for maintenance operations and establishing the maximum time of acceptable disservice).

To sum up, the main advantages of the proposed new *EI* indicator are the following:

- The capability of considering not only the number and duration of times in which the environmental indoor parameters fall outside the recommended ranges, but also the actual "distance" from such ranges;
- The use of a "response time constant", characteristic for each single work of art, which allows to take into account how the work of art reacts to the modality of variations of the microclimatic physical parameters;
- The possibility through proper weighting coefficients to consider the different impact that the environmental parameters have on the different works of art, in order to make the estimation of the damage as unbiased as possible.

CONCLUSIONS

HVAC systems are requested not only to ensure the comfort indoor thermal conditions to visitors, but also to guarantee optimal conditions of rooms where cultural goods are positioned, in line with the prescriptions for their exhibition. Hence, in case of a HVAC malfunctioning, it is important to quantify the possible damage induced to the exhibited or stored works of art. This would represent a useful information for museums' curators in the aim of properly regulating the stipulation of contracts with companies in charge of the management and maintenance of the HVAC systems, by including economic considerations related to the system's discontinuity period. The proposal presented here is a first attempt to establish a protocol to support curators in this attempt.

For this purpose, a tentative integrated, economic-wise, indicator (*EI*) was built up by means of two indexes that represent the whole time during which indoor air temperature and relative humidity fall respectively above (*IOR*) and below (*IUR*) the recommended ranges for the given work of art. The indicator is thought on the conviction that the duration of the systems failure periods is related to the possible damage occurring to the works of art. Concerning its mathematical expression, two weighting parameters, respectively, referring to air temperature and relative humidity, have been introduced, in order of considering their different impacts on the exhibited artwork.

In the paper, the new proposed indicator has been compared with the existing *TWPI* through an application to an old heritage museum building in Sicily. The comparison has shown the feasibility and the effectiveness of *EI*, while *TWPI* confirmed its almost invariance with respects to the period of interruption of the HVAC system.

In conclusion, further investigations must be carried out, especially regarding the values to attribute to the α and β coefficients, which the *EI* indicator depends on, also for better taking into account the influence of the season of the year in which the break occurs. Anyway, the role of curators and their personal knowledge of the history of the artwork in a given museum is of paramount importance for the final assessment of the *EI* index.

NOMENCLATURE

EI	economic impact indicator	[-]
IOR_{RH}	cumulated Integrate Over Neutral values of relative humidity exceeding the allowed limit	[%]
IOR_T	cumulated Integrate Over Neutral values of air temperature exceeding the allowed limit	[°C]
IUR_{RH}	cumulated Integrate Under Neutral values of relative humidity falling under the allowed limit	[%]
IUR_T	cumulated Integrate Under Neutral values of air temperature falling under the allowed limit	[°C]
PI	performance index	[%]
RH	relative humidity	[%]
T	temperature	[°C]

Greek letters

α	suitable economic weight coefficient relative to the air temperature impact	[-]
β	suitable economic weight coefficient relative to the relative humidity impact	[-]

Abbreviations

IOR	Integrate Over Neutral
IUR	Integrate Under Neutral
TWPI	Time Weighted Preservation Index

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