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# Relative humidity in the interior of concrete exposed to natural and artificial weathering

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**Abstract**

The moisture content is a crucial parameter for most of the degradation processes suffered by concrete. Thus, a certain water content is needed to develop alkali-silica reaction, frost attack, or steel corrosion, while in contrast carbonation can only progress if the concrete is relatively dry. The importance of the concrete moisture state has been studied for many years in the concrete literature, and the internal relative humidity has been addressed mainly by those researchers interested in creep and shrinkage. However, despite the numerous works on the subject, almost no data can be found on the monitoring of the moisture content or of the internal relative humidity in structures subjected to real weathering conditions. In general the extensive studies have been made in the laboratory in well-controlled chambers to examine water isotherms. In addition, modelling has been developed assuming general isothermic conditions. However, natural weathering usually implies irregular changes of temperature and relative humidity, which induce continuous nonsteady-state conditions in the interior of the concrete. In the present paper, values of the internal relative humidity of concretes submitted to natural and artificial weathering are presented. From these, it is possible to deduce that the temperature is the main factor influencing the concrete internal relative humidity in samples sheltered from rain, while rain periods are the main factor in unsheltered samples. In the environment tested, two kinds of temperature cycles are acting: the day-night cycle and the seasonal cycle. The paper discusses the phenomenological features of the observed evolution of the internal relative humidity and presents some interpretations on the mechanisms of water transport induced by the external environment. 

*Keywords:* Concrete; Aging; Weathering; Internal moisture; Temperature

## 1. Introduction

The moisture content in the concrete pores results in the progression of all kinds of physicochemical attacks on concrete. For example, the alkali-silica reaction needs a certain critical amount of moisture to develop and in cold weather, the risk of damage by frost is linked to the degree of saturation of the concrete [1].

Also, steel reinforcement corrosion, recognised at present as the most common type of damage, is moisture dependent [2]. The chlorides need water in the pores to diffuse and the carbonation only progresses below a critical moisture content [3]. Further, when the steel is depassivated, water is necessary for its progression [2,4], although saturation may lead to oxygen (cathodic) control.

After a period of wet curing, concrete moisture is the result of natural weathering. In structures directly exposed to outdoor or indoor climates, their moisture content will be the result of the local climate. Apart from submerged or underground structures, the exposed parts have a direct interaction with the natural surrounding environment.

In spite of this, almost no results are found in the literature on the moisture content of concrete exposed to natural environments. Thus, Parrott [5] and Nilsson et al. [6] have measured the internal relative humidity (RH) of samples exposed to natural weathering [5] or in contact with seawater [6]. Some other works have been made that relate to the measurement of creep and shrinkage [7–9].

In contrast, very relevant work has been carried out in the laboratory. Related to frost resistance, Fagerlund [10], Hedenblad [11], and Nilsson [12] have worked on moisture diffusivity within concrete, as well as measuring the moisture profiles generated from the external concrete surface to its interior; they have also developed analytical methods for their calculation.

Nilsson [12] and Baroghel-Bouny [13] have measured the water sorption isotherms of several cement pastes and concretes, previously studied by Feldman [14] and others.

More recently, concerning the carbonation process, Parrott [15] has monitored the internal RH of numerous sam-

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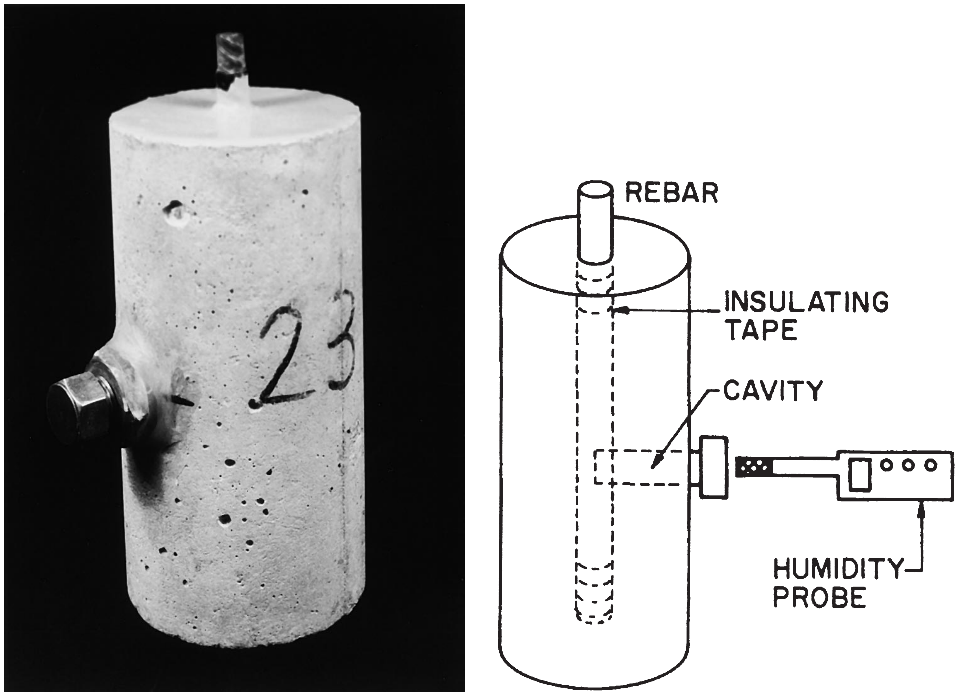


Fig. 1. The specimens used in the experiment.

ples, concluding with very interesting observations on how the internal RH (RH-IN) reaches an equilibrium.

In the corrosion field, the ambient relative humidity has been related to the corrosion current from a long time ago [2]. However, only recently some attempts [16,17] have linked the concrete moisture content, or degree of saturation, with the electrochemical parameters of the reinforcement.

All of this laboratory work uses, in general, some fixed hydrothermal [RH and temperature (T)] conditions in the external environment and waits for equilibrium of the internal moisture content of the concrete (followed by weighing the samples or waiting, for instance, to reach steady-state conditions in the corrosion rate). However, natural weather changes constantly due to the diurnal and seasonal T cycles and, from a theoretical point of view, the changes of the concrete moisture content must differ from the isothermal or well-controlled laboratory conditions.

In the present paper, results are presented on the internal RH and T (hydrothermal) behaviour of concrete specimens exposed to the Madrid outdoor climate. The results indicate that outdoor weathering induces several simultaneous water transfers in a permanent non-steady-state regime, which are far more complex than the mechanisms acting in controlled or artificial laboratory experiments.

## 2. Experimental

Although several set of specimens were fabricated, for the sake of simplicity, the results of only one will be represented. The others follow similar trends.

The specimens were cylindrical, 7.5 cm in diameter × 15 cm in height. The specimens where 3% $CaCl_2$ by weight of cement was added in the mix have been selected for presentation. They were fabricated with 300 kg of ordinary Portland cement per cubic meter of concrete and a water/cement ratio of 0.6. They were cured under water for 3 days and after this period they were exposed for 1 year to different fixed T and RH in laboratory chambers.

During this exposure, holes were drilled in the specimens to obtain a cavity in which the RH-IN could be measured. The volume of the cavity was 4.5–5 $cm^3$, with 3.5 cm in depth. The final aspect and the layout of the specimens are shown in Fig. 1.

After a 1-year period of constant T and RH, one set of the specimens was selected to be submitted to natural weathering. During this time, the internal (IN) and external (EXT) RH, T, and weight (W) were measured during different periods.

The following events were particularly studied:

- effect of extreme temperatures: artificial freezing below 0°C and heating to 40°C
- direct submission to natural or artificial rain
- drying after rain, and
- evolution sheltered from rain.

To measure the RH and T, two devices were used. One is a hygrometric sensor that continuously records the two variables RH and T. The other is a Vaisala portable hygrometer [5,11,15]. This probe has been frequently calibrated by means of introducing it in containers of standard salt solutions. During the 1-year period, no appreciable deviation has been found in the probe, which had a rather quick response and short stabilisation time.

It is well known [5,12,15] that the measurement of RH-IN is not an easy task, because in order to obtain a reliable value, it is necessary to wait until stabilisation of the probe reading. This stabilisation may take minutes or hours depending on the previous reading and, in particular, if the value itself is high (RH > 90%) it may take more than 24 h to stabilise. However, the real T changes evolve faster than stabilisation of the RH, which may make its measurement more inaccurate if not waiting.

Therefore, the procedures finally adopted were alternatively one of the following: (a) to maintain the probe permanently inserted in the cavity, to enable a smooth evolution and give accurate enough values, (b) when the permanent insertion was not feasible, the probe was previously stored in a similar RH environment to avoid sharp changes needing long stabilisation time (15 min was enough in these cases), and c) when stabilisation during a reasonable time was not possible, RH-IN values at 1–5 and 10 min were registered and graphically extrapolated to longer times using a logarithmic expression previously deduced.

## 3. Results

Fig. 2 depicts the RH/T-EXT values recorded during the period studied of 1 year. The numbers in the figure represent different events that will be studied individually.

Madrid has a climate with relatively well-marked seasons. It has a dry atmosphere that reaches values between 10–30% RH-IN in summer where rain seldom appears. Autumn and spring may be relatively mild (averaged T ≅ 15°C) with intermittent rain periods, and winter temperatures are usually around 10°C, although occasionally temperatures below 0°C and snow periods may occur.

The development of relatively extreme climatic conditions (below 0°C and above 30°C) make the Madrid climate a rather good example to enable extrapolation to other conditions. Despite Spain being considered to have a Mediterranean climate, the fact is that the country has very extreme conditions in many locations. Not only Madrid but many other locations exhibit climatic conditions that can be used to extrapolate data to many other places in far geographic regions.

In Fig. 3, the RH/T-IN have been represented together with W (changes suffered by the specimen), which was recorded mostly in the second half of the year studied. Comparison to Fig. 2 enables one to deduce, as previously reported [18], that the T-IN and T-OUT are quite similar and therefore not much attention will be paid to their differences. However, the RH-IN evolves in a very different manner than RH-EXT and therefore will discussed in detail.

With respect to the periods in which Figs. 2 and 3 have been divided, for the sake of their particular observation, the most relevant features are the following:

Period 1—The changes suffered by the T and RH-IN when submitted to daily cycles were studied during this period. Fig. 4 represents their evolution in more detail. Fig. 4 also shows the behaviour when the specimens were introduced in a refrigerator (which will be discussed later when describing period 2). Fig. 5 represents continuous monitoring of the external condi-

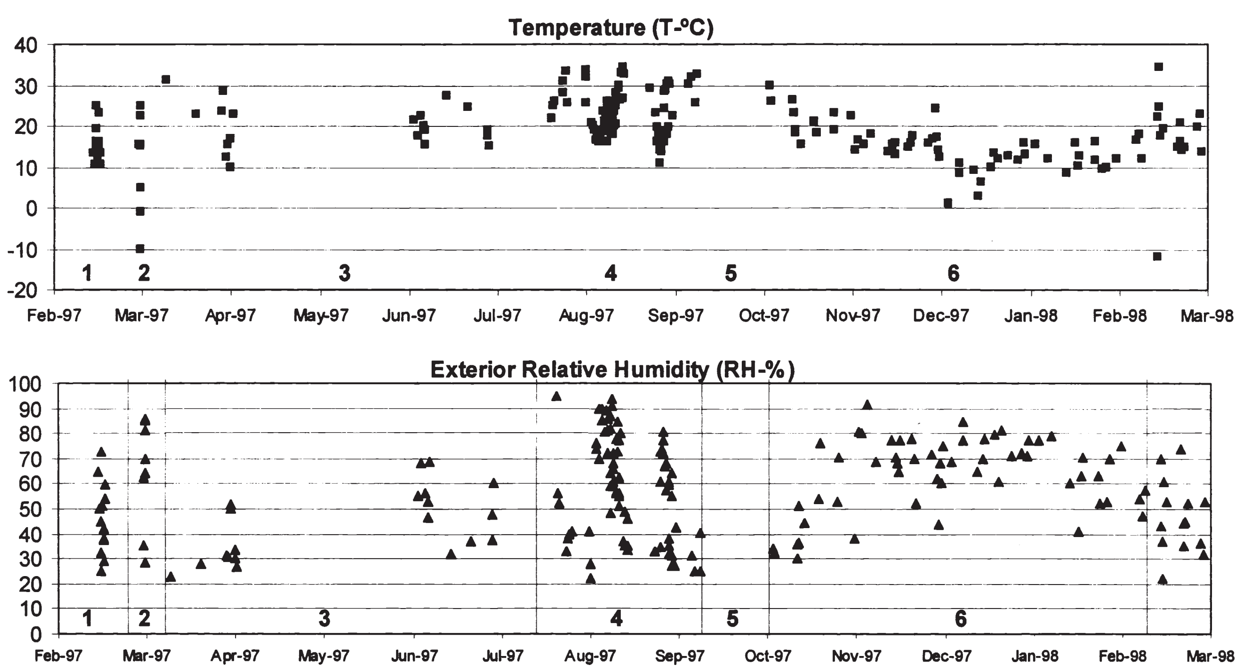


Fig. 2. RH/T-EXT values recorded during the period studied of 1 year.

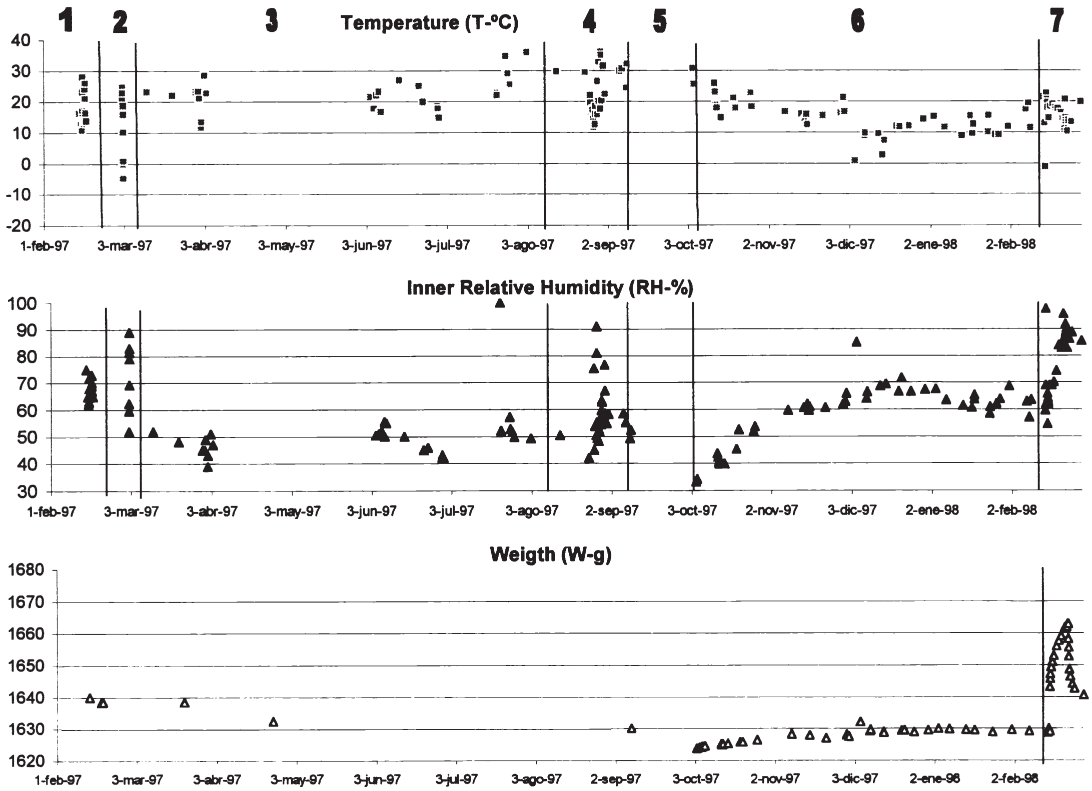


Fig. 3. Evolution along the time of internal T, RH, and weight of the specimen.

tions with the thermohygrometer during this period. It can be identified that the climate in that period of February 1997 presented a great change in T-EXT ($\Delta T$ = 17–18°C) and in RH-EXT during day and night. It is interesting to observe that the RH-IN (Fig. 4, right), however, changed very slightly, indicating that the RH-IN apparently remained very stable in spite of the wide changes of T-EXT and RH-EXT.

Period 2—During this period, the specimens were introduced in a refrigerator in order to reproduce a sudden cooling overnight (shown in Fig. 3). It can be observed that immediately after been cooled below 0°C, the RH-IN increased to >90%, although it recovers the original values immediately after the temperature is raised again.

Period 3—During this period (3 April 1997 to August 1997) the specimens were sheltered from rain and the measurements were made only in precise periods. Day-night values were only rarely registered with continuity (3 April and the beginning of July and Au-

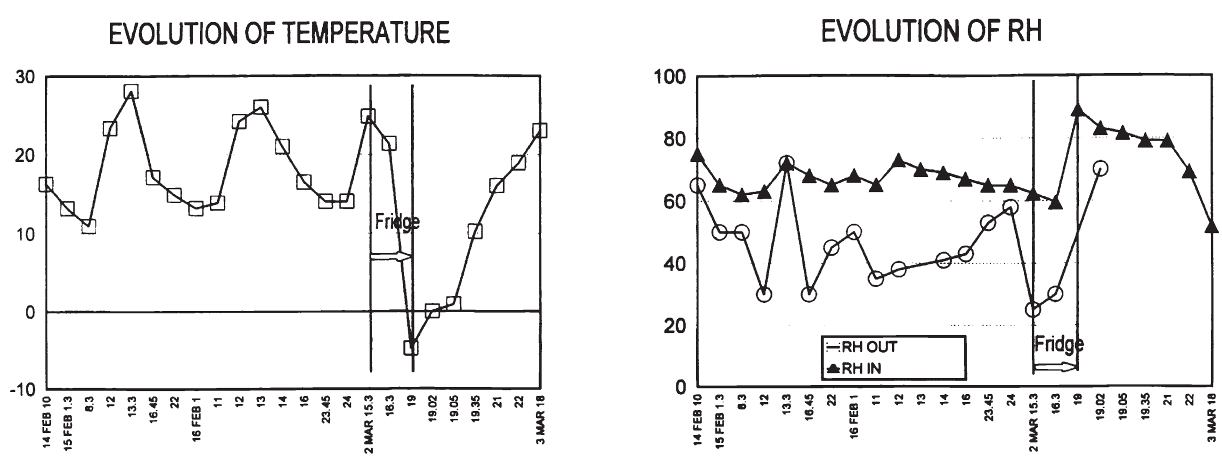


Fig. 4. A detail of the evolution of temperature and RH-IN during the day-night cycle and when introduced in a refrigerator at temperatures below 0°C.

gust). This period enables identification of the progressive evolution (drying) of the RH-IN following the increase in T typical of the summer period. Temperature reaches values above 30°C and the RH-IN falls to 40–45% during this period.

Period 4—At the end of the summer (2 September 1997) the specimens were exposed directly to the rain that fell at that time and two main features could be identified during this period, in which low temperatures are again registered during the night. The RH-IN increases during the direct exposure to rain, but falls quickly afterward. It seems as if the concrete is only superficially moistened and that when the rain stops it dries very quickly.

Period 5—In order to have an idea of the effect of high temperatures, before the summer was over the specimens were artificially heated to 40°C in chambers having 30% RH. This climate was chosen (a) to represent the average values simulating a hot climate like Madrid in summer, and (b) to quickly recover the water content that the specimens had before being submitted to direct rain. Lower RH and higher T were not used to avoid damage to the CSH-gel microstructure. The total length of this period was about 30 days.

Period 6—During this period (October 1997 to February 1998) the specimens were sheltered from rain and measurements were made every week. As the temperature steadily decreased and the RH-EXT increased progressively due to rainy periods, the RH-IN rose to values about 70%. It snowed on 3 December 1997. The T-EXT fell to values below 0°C, which induced a sudden increase of RH-IN that reached 85%. However, as soon as the T-EXT increased, the RH-IN again recovered its previous values. From October 1997, the weight was monitored simultaneously with the other measurements. It can be deduced that the increase in RH-IN from ≅30% (3 October 1997) to ≅70% (January 1998) induced an increase of only 0.33% in relation to the dry weight of the specimen.

Period 7—In February 1998, the specimens were submitted to "artificial" rain (by means of immersion in water) in order to study the effect of different lengths of rain periods. Fig. 5 only shows the response when the specimen was submerged until saturation was reached (negligible increase in weight). The total increase in W was 2.41% in relation to the dry weight. During saturation, the RH-IN increased slowly and steadily. The sudden increase in RH-IN that was detected when the specimen was submitted to natural rain was not noticed. At the end of the artificial saturation, when the weight reached a constant value, the RH-IN was permanently at ≅100%. During subsequent drying, the RH-IN decreased slowly and progressively. Also during this period, an event of artificial freezing was studied, but will not be reported here as the results were similar to the previous one.

## 4. Discussion

Before commenting on the observed hydrothermal behaviour, some fundamentals will be presented in order to justify the interpretation given later.

### *4.1. Processes occurring in the concrete during hydrothermal cycles*

In order to better imagine the processes developed, the cavity made in the specimen is represented in Fig. 6. The cavity reaches the centre of the specimen, about 3–4 cm in depth where the bar is located. The cavity walls are sealed

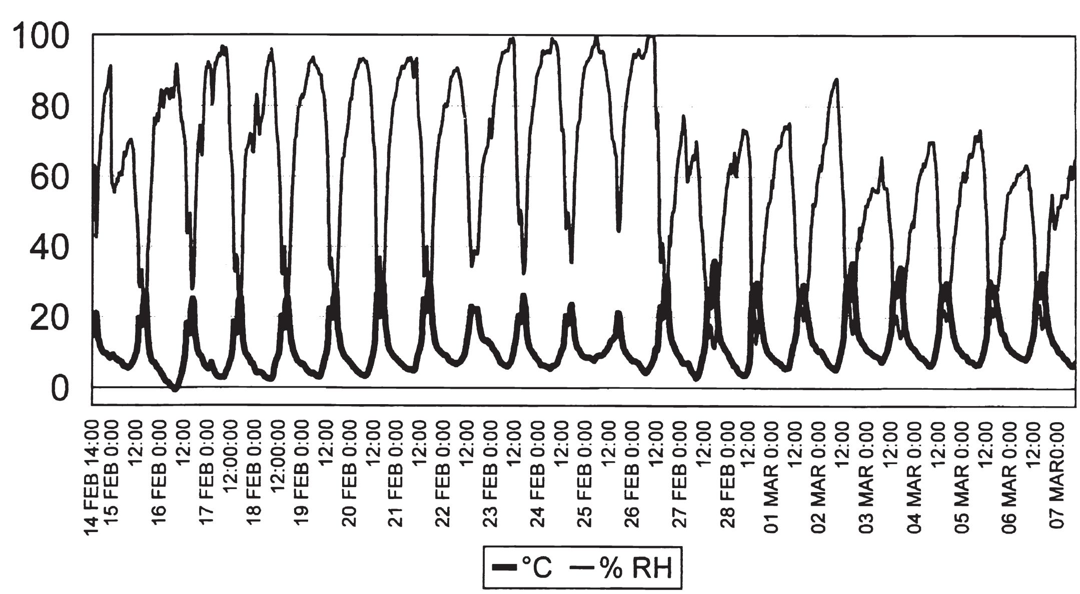


Fig. 5. Thermohygrometric monitoring of T-EXT and RH-EXT during the same period as that shown in Fig. 4.

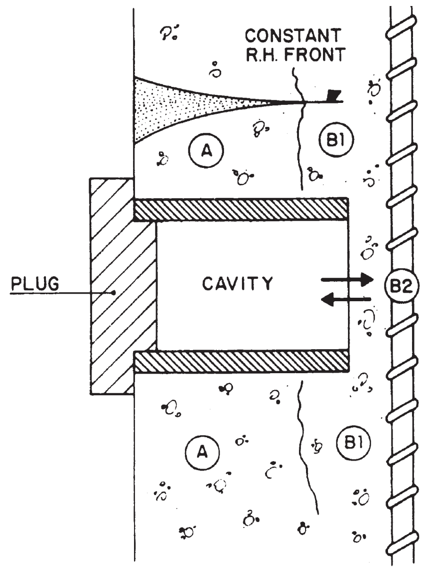


Fig. 6. Representation of the cavity made in the specimens in order to measure RH-IN. Zone B indicates the surface near the reinforcement (B2).

and therefore the exchange of water is only possible through its bottom (zone B in the figure).

This situation is now ideally reproduced by the classical representation of a pore of increasing diameter (Fig. 7). This figure enables representation of the capillary water (the only water which is exchanged with the exterior in the range of temperatures operating in present experiment). This capillary (liquid) water ($W_{evap}$) may evaporate (process I: condensation/evaporation) to form the vapour phase, which in

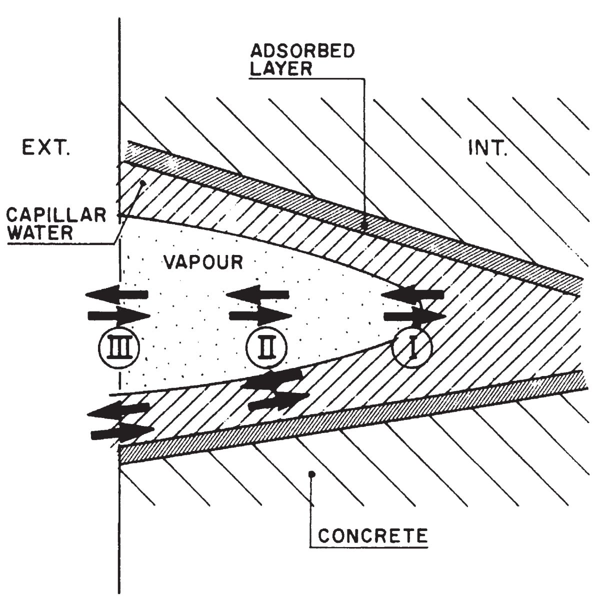


Fig. 7. Simplified representation of a pore and the processes of water (vapour and liquid) that may occur during natural weathering. Process I: evaporation/ condensation; process II: water transfer inside the concrete; process III: water transfer with the exterior environment.

turn may diffuse to the exterior in liquid or vapour phases (process II). Water can also enter the concrete by diffusion as vapour phase or by absorption when raining (process III: water exchange with the exterior).

There are, therefore, three main mechanisms involved in the water exchange with exterior: process I, evaporation/condensation; process II, diffusion of water vapour across the pore empty space (air) or as liquid phase by diffusion along the pore walls; and process III, exchange with the exterior by absorption/desorption of liquid water or water vapour.

These mechanisms can be studied by means of analyzing them following several basic laws. Two of them will be used here: (a) the so called "water isotherms" (water content-RH curves), which relate the amount of "free" water (degree of saturation) to the relative humidity (in the exterior and in the pore space), and (b) the psychrometric chart, which relates RH, T, and some other moisture characteristics. Kelvin's law, which relates the RH with the largest pore size filled with liquid water, will be not used due to the fact that this was impossible to measure.

#### *4.1.1. Evaporable water content-RH curves*

The hydric behaviour of concrete is usually studied by means of representing its water sorption/desorption isotherm. Fig. 8(a) depicts an ideal cycle of adsorption/desorption of water in concrete. Fig. 8(b) shows the effect of temperature in the sense to indicate that when temperature increases the amount of evaporable water in equilibrium with a certain RH is smaller [11–13].

It must be pointed out that the water content curves are mainly obtained in equilibrium conditions, that is, when an equilibrium between the external RH and that of the empty pore space inside the concrete is allowed to be reached at a given fixed temperature. However, this is not the case in natural or artificial weathering where the T evolves continuously. This continuous evolution of T prevents reaching an equilibrium and a permanent nonstationary regime of water transfer is established throughout the concrete cover. The water content-RH curves will be then used merely to illustrate the hygrometric changes during the different weather features studied.

#### *4.1.2. Psychrometric chart*

Although of obvious meaning, RH is a parameter not always well interpreted [19]. It represents the actual amount of water vapour $W_v$ with respect to the maximum amount $H_{max}$ that the air (or a certain empty volume) is able to accommodate at a particular temperature: $RH = W_v/H_{max}$.

The psychrometric chart (see Fig. 9) depicts this behaviour. For a certain T, if the RH ($W_v$) changes, either the maximum amount of water, $H_{max}$, or $W_v$ has to change. If a sudden dramatic change in T is produced (for instance when introduced in the refrigerator), the change in RH may not mean an effective change in the proportion of water vapour

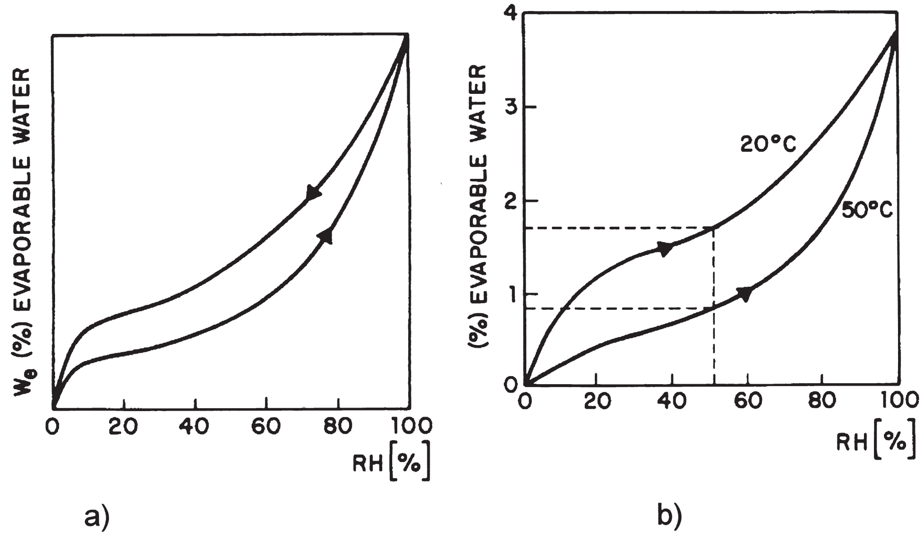


Fig. 8. (a) Adsorption/desorption water isotherms in concrete. (b) Effect of temperature in the adsorption or desorption isotherm (evaporable water content).

in the empty space of the pores. It may simply mean that the actual amount $W_v$ exceeds that of equilibrium at that temperature, and therefore the RH immediately indicates a higher value. If the concrete would remain at low temperatures, the condensation would reestablish the equilibrium by means of a continuous condensation/drying process.

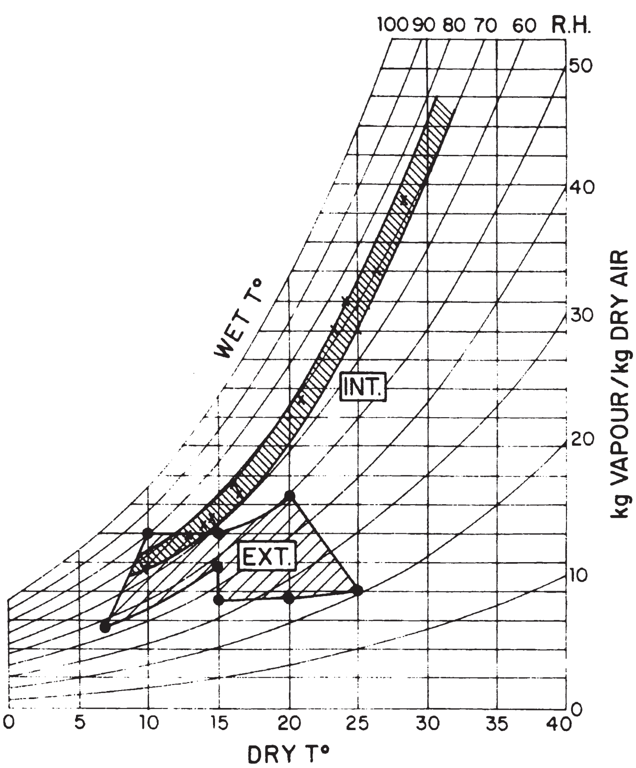


Fig. 9. Psychrometric chart representing the T/RH-IN of concrete and T/RH-EXT of the atmosphere of data shown in Fig. 4 and Fig. 5.

*4.2. Main features of weather influence*

Assuming that the model of the pore presented in Fig. 7 can be extended to represent the behaviour of the concrete cavity, four main events of the weather will be analysed:

1. the diurnal cycles
2. the long-term cycle (seasonal evolution)
3. the effect of extreme temperatures
4. the effect of rain (sheltered or not from rain)

*4.2.1. Diurnal cycles*

An example of diurnal cycles is shown in Fig. 3, period 1, and in Fig. 4. These results have been plotted in a psychrometric chart in Fig. 9. The chart represents the variation of the RH-IN of the concrete and RH-EXT of the atmosphere due to the changes in temperature in the period analyzed.

It is clear that in the external ambient, an increase in T represents a decrease in RH-EXT, because the $H_{max}$ does not change. However, in the interior of the concrete, when T increases, the liquid water evaporates ($W_v$ in the pore increases) and, as a consequence, the RH-IN remains fairly constant or increases.

Fig. 10(*a*) schematically represents the evolution of T/RH-EXT and Fig. 10(*b*) depicts the evolution of the T/RH-IN. While in the exterior, the daily cycling induces opposite trends in the RH and T parameters, in the interior they remain constant or follow the same trend.

*4.2.2. Seasonal (yearly) cycles*

This trend, however, is reversed in the long-term behaviour. Periods 3 and 5 in Fig. 3 indicate that the mean RH-IN decreases as T increases and vice versa. Concrete dries due to the progressive increase in temperature and uptakes water when the RH-EXT increases and T goes down. There is

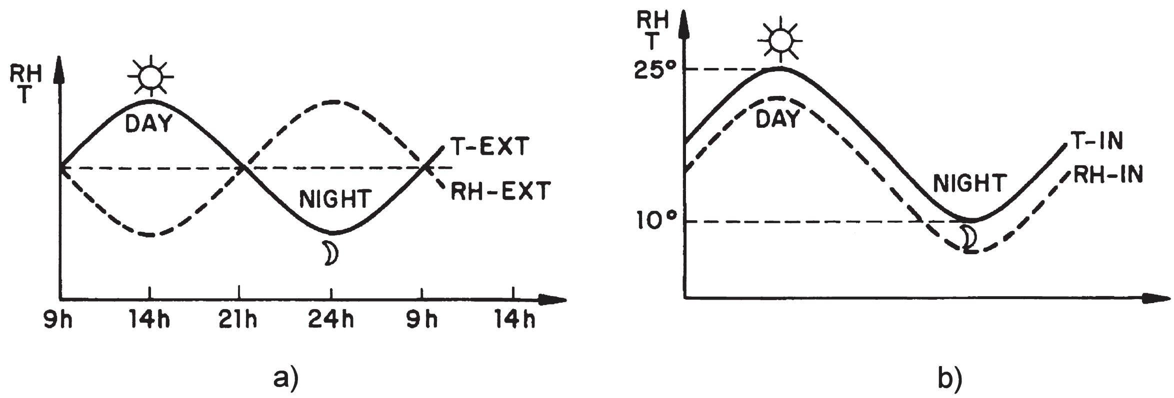


Fig. 10. Schematic representation of changes of T/RH-EXT (a) in the atmosphere and T/RH-IN (b) of concrete for the diurnal cycle.

then a year cycle in which the RH decreases during high T periods and vice versa.

Fig. 11 depicts the seasonal evolution by means of their representation as changes in the evaporable water content limited by the ideal water content-RH curves at two different seasons. In addition, the figure represents the evolution in a psychrometric chart where instead of $W_{evap}$ (degree of saturation), the hydric condition of the concrete is expressed by its RH-IN evolution.

*4.2.3. Extreme temperatures*

Either naturally or artificially, the effect of temperatures below 5–10°C and above 25–30°C were also studied (periods 2, 4, and 5 in Fig. 3). A lowering of T to values near freezing should induce a condensation of the water vapour and therefore a lowering of RH-IN. However, this does not seem to occur at the beginning because the RH increases instead of decreases. What actually happens is an apparent increase in RH because at that low T, the actual amount of water vapour, $W_v$, exceeds that of equilibrium. The situation is called "apparent" because, as soon as the T recovers its previous values, the RH-IN also reverses. There is not a real increase in the proportion of the water vapour. The behaviour is exaggerated when shown in Fig. 12(a) (period indicated during the night).

If the low temperatures remain for longer times, condensation will occur and the RH-IN will be the result of long-term equilibrium after the condensation/drying or wetting process.

The lower T, the higher will be the amount of water that may accumulate, as shown in the water content-RH curves. Regarding the pore space, this behaviour is more evident

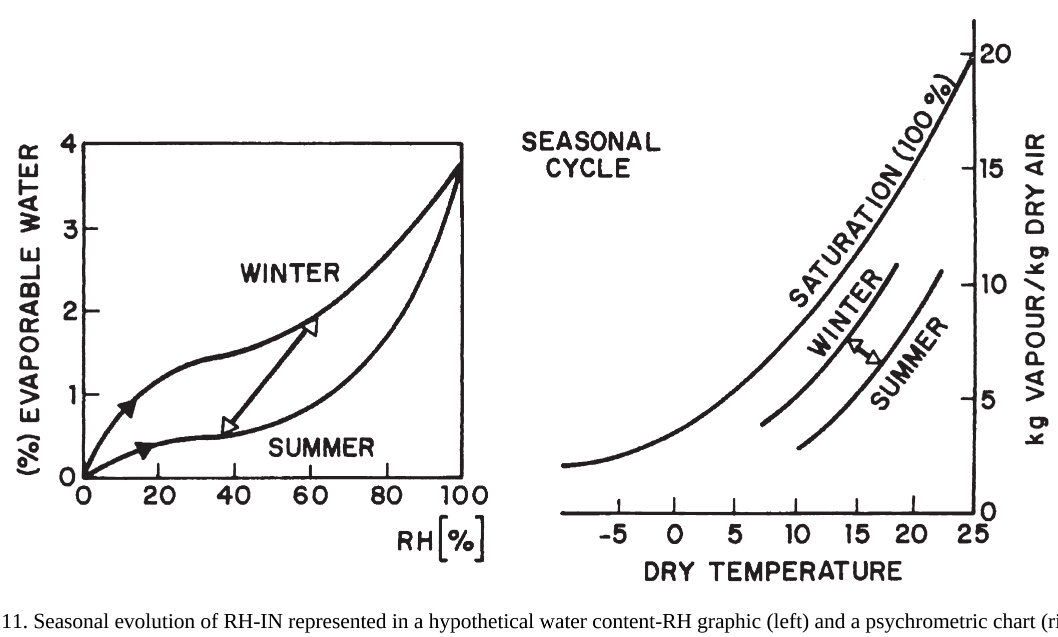


Fig. 11. Seasonal evolution of RH-IN represented in a hypothetical water content-RH graphic (left) and a psychrometric chart (right).

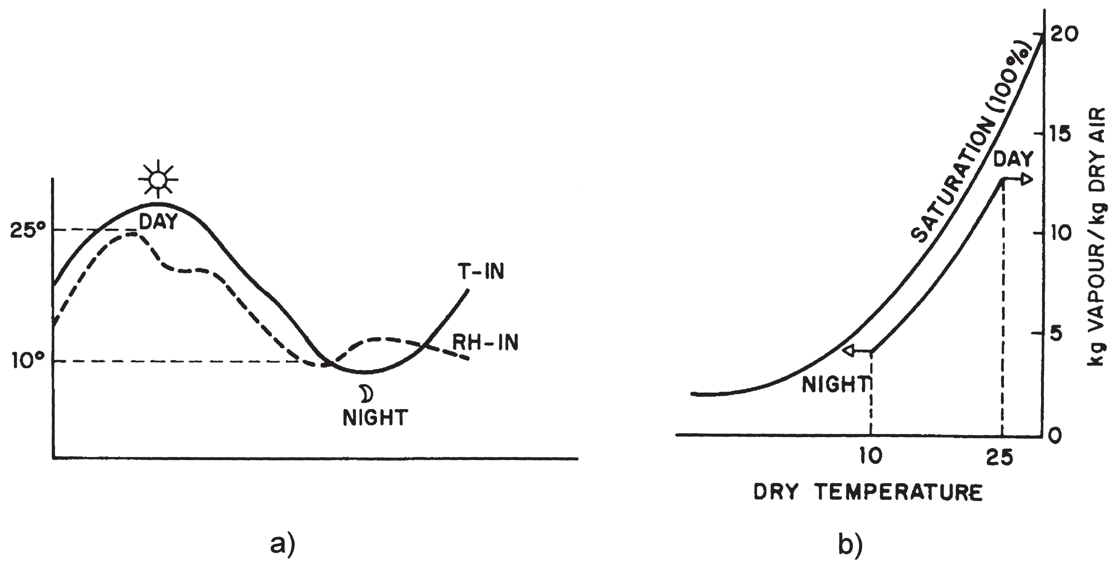


Fig. 12. Changes of RH-IN of concrete with the evolution of T, including shifts in RH-IN due to temperatures below 10°C and above 25°C (a) and represented in a psychrometric chart (b).

below 5–10°C, as indicated schematically in Fig. 12(b), because at these low temperatures saturation of the vapour is easily reached with relatively low water vapour contents [arrow at 10°C in Fig. 12(b)].

Regarding the other extreme of high temperatures, the opposite happens. At temperatures higher than 25–30°C the water evaporates in the pore space, which tends to increase the RH due to the evaporation, but this is limited when the liquid water cannot evaporate sufficiently fast. At longer terms in high temperatures, when water vapour can escape out of the concrete, the RH finally decreases. This behaviour is also exaggerated in Fig. 12(a), with an arrow at 258C in Fig. 12(b).

Thus, it can be thus summarised that the concrete behaves differently at extreme temperatures (below around 5–10°C and above 25–30°C) than in the "normal" interval.

#### 4.2.4. Effect of rain

When it rains, one would suppose that the amount of water in the concrete changes dramatically in short periods of time. It is absorbed at the concrete surface and penetrates by capillary to the interior. The drying afterward will cause a reverse water movement although, depending on the length of the rain period, not all the water taken up dries out. Part of the water and vapour diffuses towards the interior while the rest evaporates out.

Another aspect to point out is registered during period 4 in Fig. 3. A sudden increase of RH-IN during the rain period quickly recovers its previous values when the rain stopped. This was interpreted simply by a high diffusivity of water through the vapour phase, which also diffused out without real condensation during the drying. This is so interpreted because this dramatic increase did not happen when the specimens were immersed in water (period 7, Fig. 3). In this case, the increase in RH-IN took a relatively long time to happen.

A summary of the behaviour of the RH-IN of concrete not sheltered from rain is presented in Fig. 13(a). When raining, both liquid and vapour can diffuse. The final state will depend on the length of the rain period (and not on the total amount of water dropped). In the case of concrete that was sheltered from rain [Fig. 13(b)], the behaviour is similar to that shown in Fig. 13(a): the RH-IN may increase due to the increase of RH-EXT, although this increase is much less important and is sometimes negligible.

### 4.3. Hydrothermal behaviour of the concrete cavity

Two main features have to be considered when analyzing the behaviour in the cavity (assuming it can be represented by the pore model of Fig. 7): (1) the moisture content in the cavity (produced by the pores emerging from its bottom) is different than that in the exterior, as previously established [10,11], and (2) it cannot be calculated directly from the classical water isotherms, as elsewhere [20], in particular in samples not sheltered from rain, where liquid water transfer has to be considered together with the vapour exchange.

The moisture gradient existing in the concrete cover has been mainly studied by RH variation in the external atmosphere, without taking into account the T changes that, in the particular case of temperatures below 5°C or beyond 25°C, may significantly influence the rates of condensation and evaporation. Temperature evolution enters a regime of permanent nonstationary conditions of water and vapour transfer throughout the concrete cover. In addition, the effect of rain in the whole process could not be found in previ-

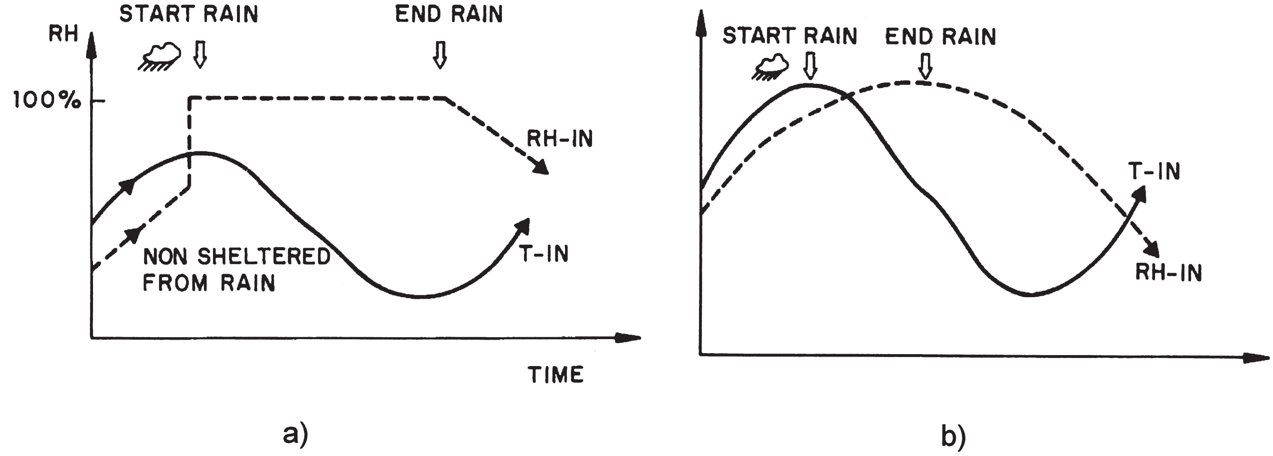


Fig. 13. Changes of RH-IN of concrete due to rain periods in a concrete (a) not sheltered from rain and (b) sheltered from rain.

ous literature, and a complete lack of data exists on the amount of rain needed to effectively influence the RH at the bar level.

The permanent nonstationary regime induced by the changes in RH, T, and liquid water prevents the possibility of calculation of the moisture gradient assuming that an equilibrium is reached between RH and evaporable water content (expressed by the water isotherms curves) inside the concrete. This equilibrium may be reached only when the amplitudes of RH and T are small, when sheltered from rain. In unsheltered conditions or when the changes of RH and T are significant, the water isotherms are only the boundary conditions of the nonstationary process. It may be deduced that only numerical methods will enable coupling of all the variables involved in the complex process of natural weathering of concrete.

The representation of the concrete water content submitted to natural weathering in samples sheltered from rain is made by means of water curves in Fig. 14(a), while in Fig. 14(b) is represented by means of a psychrometric chart. In the case of water curves, the moisture content accumulated remains in between the isotherm curves marking the boundary conditions. How close to these boundaries the water content remains will depend on the particular climate.

Finally, it has to be stressed that these deductions have been made with the particular cylindrical shape of the specimen, at 3–4 cm from a vertical concrete surface. Therefore, a precaution of proper use of the principles should be taken

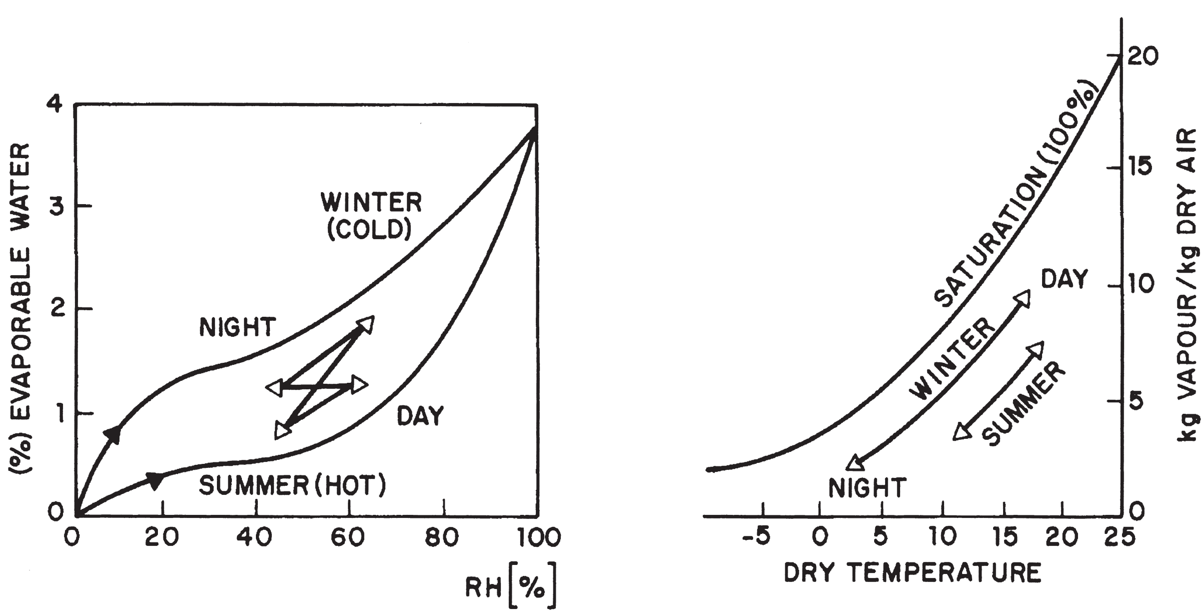


Fig. 14. Seasonal and day-night evolution of RH-IN of sheltered concrete represented in a water content-RH graphic (left) and in a psychrometric chart (right).

into account when extrapolating these conclusions to other conditions.

## 5. Conclusions

Although deductions from the results presented here seem to correspond to only one specimen, the conclusions can be extended to the whole set of specimens studied whose results have not been represented for the sake of simplicity. On the other hand, it has to be pointed out that the study has been made at a depth of 3–4 cm from a vertical surface with the particular cylindrical shape of the specimen. Therefore, the conclusions cannot be applied to smaller distances, although the fundamentals can be considered valid and precautions should be taken when applied to other conditions.

Concerning the hydrothermal behaviour of concrete submitted to natural weathering and accepting that the behaviour in the artificial cavity models the behaviour in the pores, the following conclusions can be made:

1. Water content-RH (adsorption/desorption) curves and the psychrometric chart representations have been used to interpret the hydrothermal behaviour of concrete. They have indicated that an equilibrium is usually not achieved due to the constant evolution of T and therefore, the $W_{evap}$ deduced from water isotherms (which assume an equilibrium between external and internal conditions) cannot be used to predict the hydrothermal behaviour of concrete submitted to natural weathering. It seems that a reliable prediction will only be achieved by numerical modelling able to couple the different fluxes developed by the climatic changes.
2. The RH is not an unambiguous parameter able to characterize the moisture content of concrete submitted to natural weathering, due to the fact that it does not have an univocal relation to the $W_{evap}$. In consequence it should not be used to define the moisture content of concrete exposed outdoors. The water content, $W_{evap}$, better represents the potential aggressiveness regarding the steel bar corrosion.
3. Rain and temperature are the two major events affecting moisture in concrete. In particular, the rain increases the liquid water content, inducing a dramatic difference between concretes sheltered and not sheltered from rain.
4. Four main features of climate have been identified that significantly influence the hydrothermal behaviour of concrete: (1) day-night temperature cycles, (2) yearly (seasonal) temperature cycles, (3) extreme temperatures ($<10$°C and $>25$°C), and (4) the length of rain periods.

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