# Reverberation time regulations for stairwells and corridors – A pilot study for hospitals in selected countries in Europe

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# REVERBERATION TIME REGULATIONS FOR STAIRWELLS AND CORRIDORS – A PILOT STUDY FOR HOSPITALS IN SELECTED COUNTRIES IN EUROPE

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## ABSTRACT

Comfortable acoustic conditions in healthcare environments support the well-being of patients and the working conditions of the personnel who must perform various tasks in different rooms. Corridors, stairwells and circulatory spaces are often considered secondary spaces, and insufficient attention is paid to them during the design and construction stages. Nevertheless, noise produced by different sources such as medical equipment, medical rolling carts, beepers and conversations in the corridors, stairwells, patient rooms and other adjacent rooms will propagate though corridors or stairwells and affect the people in adjacent spaces. For that reason, several countries have acoustic regulations for reverberation time or sound absorption in corridors and stairwells in hospitals.

Acoustic requirements vary widely between countries and are missing in some others. This paper compares reverberation time and sound absorption requirements for stairwells and corridors in hospitals in selected countries in Europe, and it includes up-to-date information on the applied limit values, frequency ranges and measurement methods.

## 1. INTRODUCTION

In hospitals, there is a variety of rooms with different acoustic needs. Examples are bedrooms, examination and treatment rooms, corridors, stairwells, waiting and reception areas, dining areas, offices, all with different acoustic needs, This paper analyses the reverberation time and sound absorption requirements for corridors and stairwells in hospitals of several European countries. The countries considered in this paper are: Belgium [1], Denmark [2], England [3], France [4], Italy [5]-[6], Norway [7], Portugal [8], Spain [9] and Turkey [10], thus representing various geographical parts of Europe.

Some of the countries specify very few acoustic limit values for hospitals, while others define several criteria. Instead of or in addition to a set of regulations or guidelines, some countries have hospitals included in a national acoustic classification standard with several quality levels and refer to a specific class in the standard as the acoustic regulations.

It is hoped that the room acoustic limit values in this paper could be applied for discussions, potential learning and maybe implementation of optimized limit values in acoustic regulations, guidelines or classification schemes for hospitals and other healthcare facilities.

There are more studies concerning the acoustic requirements and classification schemes related to hospitals, such as [11] about acoustic regulations and classes in the five Nordic countries for hospital bedrooms, [12] with overview acoustic sound insulation requirements in five countries in South America for housing, schools, hospitals and office buildings and [13] providing an overview of acoustic classification schemes in Europe, but with no limit values. However, none of these references deals with requirements in corridors and stairwells in hospitals, but such spaces for housing and schools are analyzed in detail in [14].

Important: The specific limit values included in this paper are the authors' interpretations from studying various national regulation documents, and the criteria in the paper must in no way be applied as proof for national limit values.

## 2. CORRIDORS AND STAIRWELLS IN ACOUSTIC REGULATIONS/GUIDELINES

Circulatory spaces in hospitals, such as corridors and stairwells usually lead to sensitive rooms such as patient rooms, special care nurseries, consulting rooms, etc. Thus, controlling noise is crucial as the detrimental effects of noise in healing environments is well documented.

Acoustic absorption in circulatory spaces aims at avoiding excessive reverberation and ensuring good communication among the hospital personnel, patients and visitors, since e.g. corridors often accommodate nursery stations, waiting areas and information desks. It also aims at limiting the noise transmitted to sensitive spaces, such as patient rooms, examination rooms, emergency rooms, offices, etc. See Figures1, 2 and 3.

Circulatory spaces in hospitals comprise corridors and stairwells, but also halls and atria. The geometry, shapes and areas of circulatory spaces vary widely and also the type of rooms they lead to.

Countries like Spain, France, England and Norway do not limit requirements/guidelines to just corridors, they include all circulatory spaces such as halls or atria leading to rooms, but in the case of atria England [15] recommends seeking the advice of a consultant. On the other hand, in Spain, enclosed stairways are excluded. In the regulations analyzed in this study there is no reference to emergency stairwells, but requirements should not apply to stairwells being exclusively used in case of an emergency, which however may seldom be the case in reality.

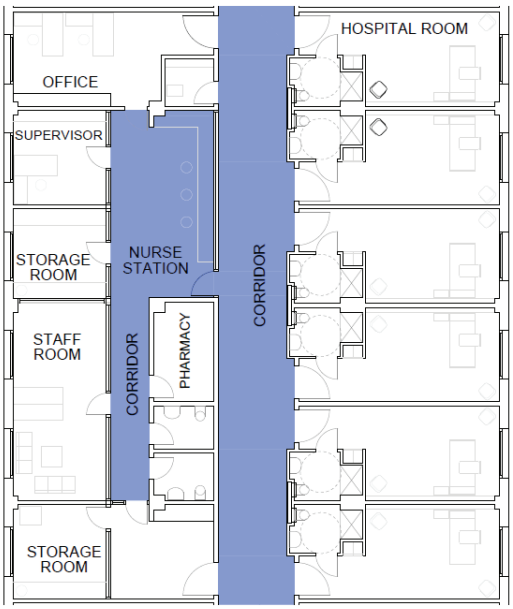



**Figure 1.** Plan view of corridors leading to hospital rooms and to a nurse station.

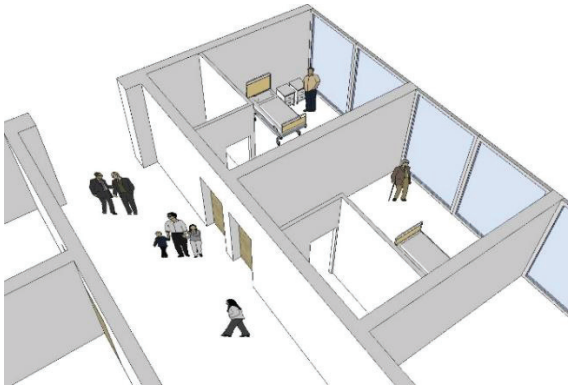


**Figure 2.** Corridor in a hospital. Excessive reverberation compromises communication in the corridor and increases noise transmitted to noise sensitive areas, e.g. hospital bedrooms.

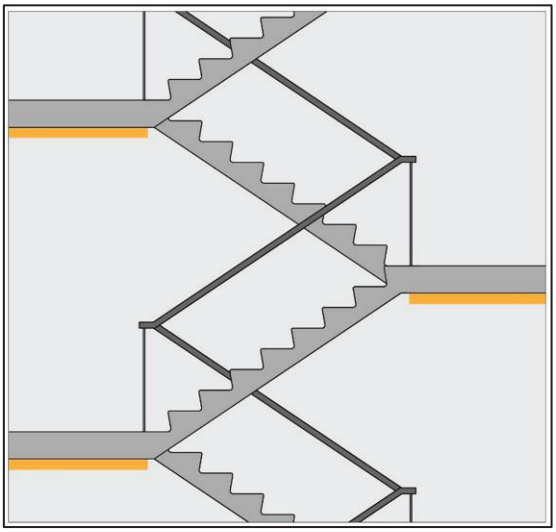


**Figure 3**. Stairwells and possible position of absorbent treatment materials to control excessive reverberation.

The acoustic criteria for stairwells and corridors in hospitals found in regulations are either reverberation time or equivalent sound absorption area. While reverberation time requirements are optimum for the verification in-situ according to EN ISO 3382-2 [15], equivalent absorption area requirements are more convenient during the design stage. EN 12354-6 [16] can be used for calculations, but some countries provide formulae, worked examples and lists of the absorption coefficients of common materials as guidelines to designers, see e.g. [3], [17], [18], [19]. The Health Technical Memorandum [3] for England is a very comprehensive document containing criteria and worked examples on how to deal with noise in health care environments.

France has also an interesting procedure for the verification of the absorption area installed in situ described in [19], consisting of inspections, checking absorption materials installed and making calculations.

## 3. ACOUSTIC REGULATIONS FOR STAIRWEELS AND CORRIDORS

The regulatory requirements for room acoustic regulations for stairwells in hospitals are found in Table 1 and for corridors in Table 2 for the selected countries in Europe. For each country, the tables indicate the limits and details of importance for design and check of compliance with the limits.

Tables 1 and 2 show that four countries, Denmark, France, Norway and Turkey, have reverberation time limits, the rest use equivalent sound absorption area. Portugal has requirements for corridors, but not for stairwells, and Italy does not have any acoustic requirements concerning corridors and stairwells in hospitals.

In Denmark and Norway, reverberation time limit values for corridors are stricter than those for stairwells, the rest of the countries do not make any distinction between corridors and stairwells in terms of acoustic criteria.

The frequency ranges considered in regulations vary from country to country. The countries requiring a minimum weighted equivalent sound absorption area, $A_w$ or a minimum weighted sound absorption coefficient, $\alpha_w$, consider the range from 250 to 4000 Hz as it is specified in EN ISO 11654 [20]. Other countries reduce the frequency range either in the low and/or the high frequency ranges as seen in the Tables 1 and 2. Norway is the only country defining the required reverberation time in corridors for the frequency ranging from 125 to 4000 Hz.

In addition to reverberation time criteria, Norway and Turkey have a requirement concerning the absorption coefficient of finishes. In the case of Norway, the mean sound absorption coefficient of the finishes in corridors must not be less than 0.15, and in order to ensure that there is enough sound absorption in the whole frequency range, there is also a limitation regarding the deviation in each octave band from the mean value. Regarding Turkey, the

weighted sound absorption coefficient of ceilings must be higher than 0.75, but this criterion is optional, if the reverberation time required in corridors or stairwells is fulfilled.

French acoustic regulations differentiate between circulatory spaces open to the public and circulatory spaces of volume bigger than 250 $m^3$ leading to hospital rooms and special care sectors. As a result, there are two sets of requirements: one consisting of a minimum absorption area and another one consisting of maximum reverberation time.

**Table 1.** Room acoustic requirements for stairwells in hospitals– Selected countries in Europe.

| **Room acoustic requirements(1) for stairwells(2) – August 2020** | | | | | |
|---|---|---|---|---|---|
| **Country** | Requirement | Furnished room | Freq. range [Hz] | Details of requirement/criterion | Comments |
| **Belgium** [1] | $A_w \geq 0.3 \cdot S_{floor}$ *Note: Draft only* | - | 250-4000 | $A_w = \Sigma(\alpha_{wi}.S_i)$ Finishes with $\alpha_{wi} \leq 0.05$ are not taken into account in the summation | Requirements under development. |
| **Denmark** [2] | $T \leq 1.0$ s *Recommendation* | + | 250-4000 | T20 according to ISO 3382-2. Max. in each 1/1 octave band | Proposed design value in the guideline linked to the building regulations, but not a requirement. |
| **England**(3) [3] | $A_w \geq 0.8 \cdot S \cdot \alpha_{wclassC}$ *Recommendation* | + | 250-4000 | Absorbers Class C according to ISO 11654 must cover at least 80% of the area of the floor. | If class A and Class B absorbers are used, the required minimum surface can be reduced according to calculations in [15]. |
| **France**(3) [4] | $A \geq 1/3 \cdot S_{floor}$ | + | 250-4000 | Min $A = S \cdot \alpha_w$; S is the surface of the absorptive lining; $\alpha_w$ from ISO 11654 | Circulation spaces of hospital rooms and care sectors. |
| | $T \leq 1.2$ s if 250 $m^3$ $< V \leq$ 512 $m^3$ and $T \leq 0.15 \cdot V^{1/3}$ (s) if V>512 $m^3$ | + | 500-2000 | T defined as the average of 500, 1000 and 2000 Hz. T20 according to ISO 3382-2 | Circulation areas accessible to the public. (With the exception of those opening to hospital rooms and care sectors). |
| **Italy** [5-6] | None | N/A | N/A | N/A | |
| **Norway** [7] | $T \leq 1.0$ s | + | 500-4000 | T20 according to ISO 3382-2. Max. in each 1/1 octave band. Deviations up to 20 % are accepted, if the mean value for the frequency range does not exceed the limit value. | |
| **Portugal** [8] | None | N/A | N/A | N/A | |
| **Spain** [9] | $A \geq 0.2 \cdot V$ ($m^2$) | - | 500-2000 | A defined as the average of 500, 1000 and 2000 Hz. | Enclosed stairwells are excluded. |
| **Turkey** [10] | $T \leq 1.2$ s | + | 250-2000 | T20 according to ISO 3382-2. The limit value must be fulfilled by the mean of results for 250-2000 Hz. | If the limit is fulfilled, the below criterion is not obligatory. |
| | $\alpha_w \geq 0.75$ for ceiling | + | 250-4000 | $\alpha_w$ according to ISO 11654. | If the above limit is fulfilled, the $\alpha_w$ criterion is not obligatory. |

(1) Overview information only. Detailed requirements and conditions are found in the references.
(2) Rooms unoccupied, unless other conditions indicated.
(3) Regulations do not include stairwells explicitly. For this paper, they have been considered circulation spaces.

**Table 2.** Room acoustic requirements for corridors – Selected countries in Europe.

| **Room acoustic requirements[1] for corridors[2] – August 2020** | | | | | |
|---|---|---|---|---|---|
| **Country** | Requirement | Furnished room | Freq. range [Hz] | Details of requirement/criterion | Comments |
| **Belgium** [1] | $A_w \geq 0.3 \cdot S_{floor}$ *Note: Draft only* | - | 250-4000 | $A_w = \Sigma(\alpha_{wi}.S_i)$ Finishes with $\alpha_{wi} \leq 0.05$ are not taken into account in the summation | Requirements under development. |
| **Denmark** [2] | T ≤ 0.6 s *Recommendation* | + | 250-4000 | T20 according to ISO 3382-2. Max. in each 1/1 octave band. | Proposed design value in the guideline linked to the building regulations, but not a requirement. |
| **England**[3] [3] | $A_w \geq 0.8 \cdot S \cdot \alpha_{wclassC}$ *Recommendation* | + | 250-4000 | Absorbers Class C according to ISO 11654 must cover at least 80% of the area of the floor. | Design values for hospitals, but not a requirement. If class A and Class B absorbers are used, the required minimum surface can be reduced according to calculations in [15]. |
| **France** [4] | $A \geq 1/3 \cdot S_{floor}$ | + | 250-4000 | Min A = $S \cdot \alpha_w$; S is the surface of the absorptive lining; $\alpha_w$ from ISO 11654 | Internal circulation spaces of hospital rooms and care sectors. |
| | T≤ 1.2 s | + | 500-2000 | | Reception areas accessible to the public. |
| | T≤ 1.2 s if 250 $m^3$ < V ≤ 512 $m^3$ and $T \leq 0.15 \cdot V^{1/3}$ (s) if V > 512 $m^3$ | + | 500-2000 | T defined as the average of 500, 1000 and 2000 Hz. T20 according to ISO 3382-2. | Halls and corridors, circulation areas accessible to the public. (With the exception of those opening to hospital rooms and care sectors). |
| **Italy** [5-6] | None | N/A | N/A | N/A | |
| **Norway** [7] | T ≤ 0.27·h (s) h = room height (m) | + | 125-4000 | T20 according to ISO 3382-2. Max. in each 1/1 oct. band. For 125Hz, +40% accepted. For 250-4000 Hz, deviations up to +20 % accepted, if the mean value for those frequencies does not exceed the limit value. | Additional criterion for $\alpha_{mean}$, cf. [7], see below. |
| | $\alpha_{mean} \geq 0.15$ | – | 125-4000 | Min. in each 1/1 octave band. For 125 Hz, a reduction up to 40% accepted. For 250-4000 Hz, deviations up to 20 % accepted, if the mean value for 250-4000 Hz does not exceed the limit value. | $\alpha_{mean}$ is determined using data for all surfaces in unfurnished rooms, i.e. floors, walls and ceilings. |
| **Portugal** [8] | $A \geq 0.25 \cdot S_{floor}$ ($m^2$) | - | 125-2000 | A defined as the average of 125 to 2000 Hz | |
| **Spain** [9] | $A \geq 0.2 \cdot V$ ($m^2$) | - | 500-2000 | A defined as the average of 500, 1000 and 2000 Hz. | Requirements apply only to corridors leading to patient rooms. |
| **Turkey** [10] | T ≤ 1.2 s | + | 250-2000 | T20 according to ISO 3382-2. The limit value must be fulfilled by the mean of results for 250-2000 Hz. | If the limit is fulfilled, the below criterion is not obligatory. |
| | $\alpha_w \geq 0.75$ for ceiling | + | 250-4000 | $\alpha_w$ according to ISO 11654. | If the above limit is fulfilled, the $\alpha_w$ criterion is not obligatory. |

(1) Overview information only. Detailed requirements and conditions are found in the references.
(2) Rooms unoccupied, unless other conditions indicated.

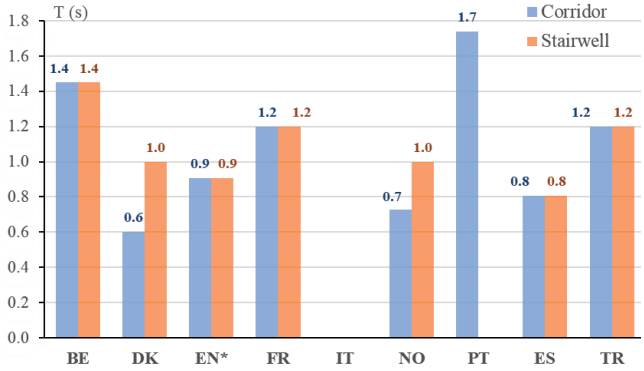
## 4. COMPARING REGULATIONS

As seen from Tables 1 and 2, descriptors vary among countries, and in some cases, requirements are expressed as a function of the walkable surface, height or volume of the rooms. To allow for comparison, requirements from the countries analyzed have been applied to a corridor and a stairwell of a real hospital in Madrid. Dimensions of the spaces considered in the calculations are shown in Table 3.

**Table 3.** Stairwell and corridor dimensions used in the calculations.

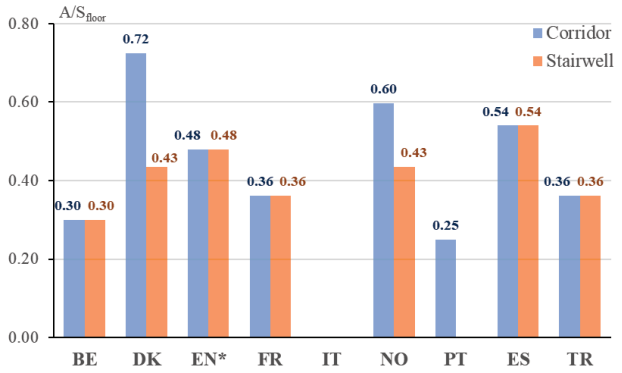
| Space | Floor surface ($m^2$) | Height (m) | Volume ($m^3$) |
|---|---|---|---|
| Stairwell | 22.5 | 2.70 | 61 |
| Corridor | 154 | 2.70 | 416 |

Figure 4 shows the values of the reverberation time required for a corridor and a stairwell. Figure 5 shows the ratio of the equivalent sound absorption area to the floor surface for the same stairwell and corridor. In the conversion between descriptors, the Sabine equation has been used and it has been assumed that the calculated sound absorption areas are single values, so Figures 4 and 5 show an approximate estimation of which requirements are stricter.




* The rev. time was calculated for a min. $\alpha_w$ of a class C absorber. ($\alpha_w$ = 0.6)

**Figure 4.** Estimated reverberation time required for an example (case) of a stairwell and a corridor in a hospital.




* $A/S_{floor}$ was calculated for a minimum $\alpha_w$ of a class C absorber. ($\alpha_w$ = 0.6)

**Figure 5.** Estimated $A/S_{floor}$ ratio required for an example (case) of a stairwell and a corridor in a hospital.

Figure 4 shows that the reverberation time limits vary significantly for both types of spaces: from 0.6 s to 1.7 s in corridors and from 0.8 s to 1.4 s in stairways. For the corridor, Denmark has the lowest reverberation time, whereas the requirements of Spain result in the lower reverberation time for stairwells. The mean reverberation time obtained for this example (case) is 1.1 s for corridors.

As a result, the ratio of the equivalent sound absorption area to the floor surface also varies greatly, from 0.25 to 0.72. Denmark gets the highest $A/S_{floor}$ for corridors, whereas for stairwells Spain requires the highest sound absorption area to surface floor ratio: 0.54. The average ratio of $A/S_{floor}$ in this example results in 0.43 for stairwells and 0.46 for corridors. See Figure 5.

For the same space, requirements vary widely from country to country, which means that the perception of each space in each country will be different, and also the finishes or materials will differ.

## 5. DISCUSSION, CONCLUSIONS AND SUGGESTIONS

Controlling excessive revberation in circulatory spaces such as corridors and stairwells plays a vital role in hospitals, as it ensures good communication in these spaces. Corridors often include waiting rooms or nurse stations, and it is important to reduce noise transmitted to noise sensitive areas, such as hospital bedrooms or consultation rooms.

For that reason most countries have such regulations for hospitals. In this paper, the regulations of nine selected countries have been analyzed. Two of them, Denmark and England, do not have mandatory regulations, but have guidelines, which have been included in this study.

As for housing and schools [14], the two room acoustic criteria for stairwells and corridors in hospitals in the regulations of the selected countries are reverberation time and equivalent sound absorption area. While reverberation time can be measured in situ and allows in-situ verification of requirements, sound absorption is easier to apply during the design stage of a building.

Norway, Denmark and Turkey have reverberation time limit values, whereas the rest have sound absorption area limits. France has also reverberation time requirements for circulatory spaces that are accessible to the public if the room volume is bigger than 250m$^3$, but requires a minimum sound absorption area in the case of corridors connecting hospitals bedrooms and healthcare areas. Most countries do not make any distinction between corridors and stairwells in terms of acoustic criteria, as these spaces are considered circulatory spaces. Only in Denmark and Norway, reverberation time limits for corridors are stricter than the requirements for stairwells.

Regardless of the type of requirement, reverberation time or sound absorption area, the following aspects vary among countries, which make comparisons difficult.

- Frequency ranges: For sound absorption, most countries consider the range from 250 to 4000 Hz, especially those countries requiring a minimum weighted sound absorption coefficient, $\alpha_w$, as it is specified in EN ISO 11654 [20]. – But France, Spain and Turkey reduce the frequency range either the low frequencies and/or the high frequencies. Norway is the only country considering frequencies ranging from 125 to 4000 Hz in corridors.
- In Norway and Denmark, reverberation time limit values must be met in each octave band, in the case of Norway, some deviations are permitted, see Tables 1 and 2. In France and Turkey, reverberation time is expressed as the mean value for a certain frequency range.
- In Belgium, England, France, Spain and Portugal, the sound absorption area is expressed as a single number. Except for Spain and Portugal, all countries refer to weighted values according to EN ISO 11654 [20].

Differences in descriptors and frequency ranges hinder comparisons. In addition, requirements are expressed as a function of the walkable surface, height or volume of the rooms. Section 4 shows a comparison of requirements

when they are applied to a specific stairwell and a corridor, and the following conclusions have been reached:

- Reverberation time limit values vary considerably, from 0.6 s to 1.7 s in corridors and from 0.8 s to 1.4 s in stairwells. The average reverberation time obtained for the case is 1.1 s.
- The ratio of the equivalent sound absorption area to the floor surface also varies greatly, from 0.25 to 0.72. Denmark is the country requiring the largest sound absorption area and the lowest reverberation time in corridors, whereas the average ratio of $A/S_{floor}$ in this example results in 0.43 for stairwells and 0.46 for corridors.

These variations found in the resulting limit values will lead to a different perception of the spaces and different construction solutions among countries. It could be suggested to initiate a discussion in Europe about experiences from different ways to specify the requirements and to prepare some optimized sets of requirements.

In [13] is provided an overview of acoustic classification schemes in Europe for various buildings, including hospitals. Since stairwells and corridors are included in different ways and in some cases not all, it is suggested to make a more detailed study of the schemes and to suggest upgrades for the next revisions. Such studies could also be useful for improvements of various sustainability building certifications

## ACKNOWLEDGEMENTS

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Important note: The specific limit values and recommendations included in this paper are the authors' interpretations from studying various national regulation documents (although in some cases assisted by national experts). The criteria in the paper must in no way be applied as proof for national limit values, but current regulation documents and detailed conditions must be consulted.

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