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PROPOSED REVISION OF REVERBERATION TIME BY INTERNATIONAL CODE COUNCIL FOR CLASSROOMS WITH CHILDREN DEAF/HARD OF HEARING

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ABSTRACT

This presentation will describe a current proposal to the International Code Council in the United States by a multidisciplinary group to further limit classroom reverberation time (RT) to a maximum of 0.4 seconds from the current building code specifying 0.6 seconds. This presentation will first address the central role of the International Code Council in American school design. A review will follow of the rationales substantiating this requested reduction. Research literature indicates that a reduction in RT below 0.6 seconds benefits children with typical hearing, but the benefit is usually statistically non-significant. At the same time, the benefit to children with hearing loss and wearing hearing aids or cochlear implants is significant and substantial. This group's calculations based on built classrooms and computer models indicate that this reduction in RT would add less than 1% to total construction costs. A decision by the International Code Council on this requested change is expected prior to Forum Acusticum 2023.

Keywords:, *reverberation, classroom, building code*

1. INTRODUCTION

Nationally-developed building codes in the United States (US) provided by the International Code Council (ICC) in its publication ICC A117.1 address the classroom acoustic needs of children with typical (normal) hearing but do not address the needs of children who are deaf and use cochlear implants or who are hard of hearing and use hearing aids [1]. The American National Standards Institute (ANSI) and the Acoustical Society of America (ASA), in contrast, include in ANSI/ASA S12.60-2010/Part 1 that classrooms be readily adaptable from the standard of 0.6 seconds (s) to 0.3 (s) reverberation time (RT) in classrooms of volumes 283 m^3 (10,000 ft^3) or less for children who are deaf and hard of hearing (D/HoH) [2]. A multidisciplinary team presently has a proposal before the ICC to revise its ICC A117.1 Section 808 "Enhanced Acoustics for Classrooms" to reflect more the intent of the ANSI/ASA standards to accommodate the listening needs of children who are D/HoH. The reason for the focus on ICC A117.1 comes from interviews with architects and code specialists in three regions of the US. They report that, when designing disability accommodations for a school, they refer not to standards in ANSI/ASA S12.60 but to the model codes in ICC A117.1.

2. PROPOSAL DEVELOPMENT

2.1 Overview

The team is proposing to the ICC that A117.1 Section 808, in addition to the acoustic classroom-building code of a maximum 0.6 s RT, also require the built-in readiness for future additions of acoustic treatments to reduce RT to 0.4 s. The classroom must be designed, in other words, for situations occurring in the classroom after construction is completed and the architect is no longer involved. When the school is later occupied, a child with a hearing-related issue may be assigned to the classroom who is identified through their education plan as in need of reduced RT. The classroom has been built for the ready installation of the necessary additional acoustic materials.

2.2 Background

Prior to the founding of the ICC in the 1990s, several independent code organizations across the US provided model building codes on a regional basis. The purpose of

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the subsequent ICC was, and is, to publish national codes. Today, standards development requires a process of, another other steps, openness, due process and consensus that are approved by ANSI and recognized by the US federal government [3]. Consensus can be challenging given that the ICC identifies multiple interest groups for representation on a committee. These may include, in acoustics code development, entities such as manufacturers, builders, designers, consumers, public advocates, and government regulators among others. Any newly proposed code or revision must meet the approval of a large majority of these participating entities while accomplishing its purpose of providing meaningful accessibility.

2.3 Current challenges

The new or revised code must provide the architect and code specialist with precise instructions easy to understand and apply so that there are no questions as to *how* to comply with the code so that their work will pass code inspection and occupancy can be granted. The ANSI/ASA S12.60/2010-Part 1currently provides *what* is needed in classroom acoustics. The challenge is that S12.60 uses such terms as "readily adaptable." Though most people may reasonably agree to the meaning of readily adaptable, the term can be interpreted in various ways and is thus unacceptable for the demanding purposes of the ICC. As another example, the term "appropriate documentation" is considered too open to interpretation and thus unacceptable for use in the context of building code.

This translation from *what* is needed as described by standards to the *how* described in building code has required a multidisciplinary team. The team consists of an architect, Stephen Wilson, and an acoustical engineer, Andy Carballeira, both with experience in the design and construction of schools; an audiologist/consultant/writer, Cheryl DeConde Johnson, on hearing loss in educational settings; and an audiologist/researcher, the author, in children's perception of speech in classroom acoustics. Due to the challenge of writing building code, progress has been possible with the guidance of several ICC committee members, especially Marsha Mazz.

Another challenge in the development of building codes within the ICC is that it publishes accommodation code in its document, A117.1. The ICC, however, also publishes the International Building Code (IBC). For the purposes of accommodation, any limit on which classrooms, other than size, to which the codes apply must be described in the IBC, and then the code for the specific design of those classrooms is provided in ICC A117.1. An analogy may be helpful. To design a parking lot to code, a certain percentage of spaces must be handicap accessible. That percentage is provided in the IBC. The design and technical requirements of each parking place, on the other hand, are provided in ICC A117.1. The architect or specialist is guided by the IBC to refer to ICC A117.1. The process for submitting and gaining approval for a proposed code change for the ICC A117.1 is completely separate from the IBC. Proponents of code change should be mindful that ICC A117.1 updates or reaffirms about every five years, while the IBC is every three years, and thus their release schedules usually do not coincide. It can save years, therefore, to write a proposed code or revision that applies to all situations that it addresses, and thus, for disability accommodation, goes only through the ICC.

The ICC A117.1 committee processes proposed code and revisions for many issues other than hearing loss and classroom acoustics, such blindness and mobility. Within each five-year cycle, there are only a few opportunities to make, receive constructive criticisms of, and then amend any one proposed code or revision. One has to approach the ICC committee with thorough preparation. Otherwise, a proposal may be rejected and one then must wait until the next cycle begins. The new cycle would not complete for another approximately five years.

2.4 Methods proposed to assure code compliance

To provide acoustic accommodation for children who are D/HoH, the team proposes to ICC A117.1 that the architect follow either one of two methods of compliance. One method is by "performance." This method allows the architect to design the classroom and later, after completion, measure for performance that meets the code, including the readiness for modification to 0.4 s RT. The second means is "prescriptive." This method allows for acoustic design of the classroom in advance of construction and does not later require field verification. Provided are specific descriptions of materials and a formula based on room size, noise reduction coefficient ratings, placement, and so forth. This formula allows the architect to determine the appropriate amount of space and location of additional acoustic material by which to attain 0.4 s RT when needed in future occupancy. The team chose the target of 0.4 s RT due to the estimated high cost of reducing RT from 0.4 s to 0.3 s, and with the prediction that the RT of an unoccupied classroom of 0.4 s would likely reduce closer to 0.3 s when occupied [4; 5, derived from Table 2]. The architect is assured, by use of either one of these two methods, that their design will be in compliance with ICC A117.1 and provides future accommodation of children who are D/HoH.

2.5 Process of code approval

In its initial step in the approval/disapproval process, the ICC posted our first proposal for public comment. The resultant public comments expressed no major criticisms, but the ICC committee advised the team that some of the wordings still lacked sufficient specificity or were unacceptably open to interpretation. Any subsequent revision, however, had to adhere closely to the intent of the originally proposed revision that had already gone through the initial public review. The reason to adhere closely is that, in its commitment to openness, the ICC seeks to allow any interested party to assess, during initial public review, a proposal's acceptability. If found acceptable, that party may then step out of the development process. The ICC requires that any interested party be able to feel confident in the openness and consistency of the ICC. The ICC therefore will allow only relatively minor subsequent changes and none beyond the intent of the proposed code or revision originally posted for public review.

The team subsequently submitted a revised proposal, and the ICC committee recently voted near-unanimously its approval to move the proposal to the next phase. The next phase begins with a second public review, which is occurring at the time of this writing. The ICC is expected then to take a final vote, possibly before Forum Acusticum 2023 meets in Torino. If approved, the next edition of ICC A117.1 to include these revisions likely may be published by 2024. The revised ICC A117.1 will be referenced by the IBC, likely in 2027. States and jurisdictions usually take several more years beyond publication to adopt new IBC (and, therefore, ICC) codes. It may be 2030 before classrooms are designed to reflect the new codes and revisions and include this proposed revision addressing 0.4 s RT. Furthermore, a state or jurisdiction may choose to adopt only parts of a model code, which reportedly occurs with a majority of states. Advocates for children in the classroom would then need to petition for local adoption of an ICC-approved code change. The prestige of the ICC, however, is expected to facilitate such efforts.

2.6 Literature review

The team's proposed code revision focuses on a relatively small difference in RT of between 0.6 s and 0.4 s. Many classrooms in North America likely may have RTs approximating this range. Measurements in 220 K-12 unoccupied classrooms in the US indicate 85% have RTs of 0.6 s or less, and about one-third have RTs approximating 0.4 s [6]. Similar RTs, and with an average occupied RT of 0.41 s, have been reported in a sample of 30 Canadian elementary classrooms [7].

Studies of the effects of RT on children in the classroom address a range of issues including well-being, reading ability and, often, perception of speech. When the focus has been on the narrow range of RT, 0.6 s to 0.3 s, speech perception scores seem to have been the metric of choice. The data reveal that this small reduction in RT is of statistical significance and provides meaningful benefits to speech perception in children who are D/HoH [8,9]. These findings are in agreement with similarly significant patterns that emerge for these children when test conditions compare speech perception from, for example 0.6 s or 0.4 s RT, to anechoic conditions [10,11]. Though anechoic conditions are not applicable to classrooms, the patterns of improved speech perception scores when reverberation is reduced to elimination is in agreement with results observed when RTs are simply reduced.

These and other studies using similar listening conditions report benefits, though more limited, to speech perception in children with typical hearing as well. Reductions in RT from 0.6 s to 0.3 s provided benefits in perception of speech to these children, either non-significantly or significantly depending on the study [8,12]. "Acceptable" RTs in classrooms are reported as ranging from 0.9 s to 0.3 s [13]. Others report the benefits of RTs below 0.7 s, with 0.4 s used as an example, as support for children's perception of speech in noise when compared to listening in RTs 0.7 s and longer [14].

The beneficial role of early reflections in the clarity of speech is well established. Studies have examined early reflections across various RTs using several parameters: the level of the reflected sound arriving at the listener's ear within 50 msec of the direct sound, the level of the early reflections in relation to later-arriving reflections, and/or in relation to background noise, and so forth. For children's perception of speech in the classroom, studies using mathematical models to examine these parameters report RTs at, or including, 0.3 s RT as optimal [4,15].

Reduction of RT may raise important concerns that early acoustic reflections beneficial to the perception of speech may be reduced to the extent that students in the rows furthest from the front of the room may not hear the teacher well. This potentially detrimental effect is recognized as occurring in classrooms larger in volume than the ones to which this team's proposal applies, 283 m^3 (10,000 ft^3) or less. In recognition of the benefits of early reflections, building standards and codes specify longer maximum RTs (0.7 s or longer) for classrooms of volumes greater than 283 m^3 (10,000 ft^3) up to and including 566 m3 (20,000 ft^3) and greater than 566 m3 (20,000 ft^3). These codes and standards require comparatively shorter RTs for smaller classrooms of 283 m^3 (10,000 ft^3) or less [1,2]. Mathematical models of the listening needs of children seated throughout a simulated classroom have examined the relationship between early reflections, later-arriving reflections and detrimental noise [16]. Considered in the calculations were nine positions of students throughout the classroom, including three in the backrow and furthest from the voice source, the teacher, calculated as always at the other end of the classroom. It is notable that the classroom was larger, 336.6 m^3 (11,887 ft^3), than those, 283 m^3 (10,000 ft^3) or smaller, specified in this team's proposal and in acoustic standards and codes for an RT of 0.6 or 0.3 s. The simulated classroom was also much larger than the average size of many classrooms in North America reported as approximately 198 m^3 (7000 ft^3) [4,17]. The longer distance from teacher to back row in the simulated larger room may emphasize more the need for maximal early reflections compared to that in smaller classrooms. The conclusion from the simulation, nevertheless, is that RTs for maximal speech intelligibility are from 0.6 s to 0.3 s. From these results, it appears that the threshold in room size above 283 m^3 (10,000 ft^3) where RTs longer than the 0.3 s may benefit the perception of speech is in need of further study.

The effects of classroom reverberation, especially relatively long RTs, on teacher vocal effort and thus vocal health has been of important concern for many years [18]. Studies report that reducing long RTs (e.g., 1.2 s to 2.0 s) down to mid-range RTs of semi-reverberant classrooms, 0.7 s, reduces vocal effort and thereby may benefit teacher's vocal health [e.g., 19,20]. In comparatively shorter RTs (i.e., 0.5 s and 0.4 s), teachers may increase measured and self-reported vocal effort [20]. Despite this strong evidence, others report that teachers experience less vocal effort when RTs are reduced from 0.8 s to 0.4 s [21]. Relatedly, classrooms with RTs in the range of 0.7 have been associated with elevated noise levels, disturbance and teacher annoyance compared to experiences in classrooms with much shorter RTs [18]. Others have studied measurable indicators of teachers' stress in the classroom such as heart rate in relation to RT [22]. Teacher's heart rate is reported as less elevated in classrooms with RTs shorter than 0.5 s for a significant amount of the school day compared to time spent in classrooms of greater than 0.5 s RT. One approach suggested is to compromise and balance teachers' vocal health with children's perception of speech, and thereby design classrooms RTs in the range of 0.45 s to 0.6 s [23].

It would be reasonable to investigate whether teachers benefit the children's learning process by raising their voices in low RT classrooms. That is, do they need to increase vocal effort? This author could not locate any research that investigated whether teachers raise their vocal effort in low RTs (e.g., 0.4 s) because they are accustom to the reflected loudness of their voice in longer-RT classrooms (e.g., 0.7 s). Do teachers produce vocal effort in low classrooms RTs in response to their voice sounding softer, even though their voice may actually be more intelligible to the children compared to when listening in higher-RT classrooms? Is it possible that voice training for application in low-RT classrooms may be advantageous to both the teacher's voice and, with the low RT, the children's perception of speech? Would teachers' vocal health be well supported by further definition in building code of acoustic materials and placements to further support early reflections of the teacher's voice while reducing detrimental acoustic reflections? Support for teachers' vocal health is paramount. The solutions that benefit both teachers and children in the classroom, however, may be best defined only through further investigation. Future code revisions will need to reflect the insights gained from these investigations.

2.7 Cost

The cost of reduction in RT from 0.6 s to 0.4 s is estimated as follows. A typical North American classroom of 198.2 m^3 (7000.0 ft^3) with ceilings 3.0 m (10.0 ft) high will have a floor area of 65.0 m^2 (700.0 ft^2). The additional area of acoustic panels (NRC = 0.80) to reduce RT from 0.6 s to 0.4 s is calculated as 30% of the floor area, or 19.5 m^2 (210.0 ft^2). The current approximate cost in the northeastern US to cover this 30% area is €244.8/m^2 ($25/$ft^2$), including materials and labor. For one classroom, the total would be €4774 ($5246). If cost of a new school is budgeted at €20,020,000 ($22,000,000; based on two schools constructed in mid-western US in 2021-2022) with 35 classrooms in the school, the total cost of reducing RT from 0.6 s to 0.4 s in *all* of a school's classrooms would be 35 times €4774 ($5246), or €167,090 ($183,610).

This is 0.83% (less than 1%) of the total cost of a new school.

3. CONCLUSIONS

To modify the US model building codes to allow, when needed, the reduction of classrooms RTs from the current maximum of 0.6 s to 0.4 s may very likely provide substantial benefit to speech perception in children who are D/HoH. Benefit, to a more-limited degree, may very likely extend also to children with typical hearing. The optimal balance of early and late reflections is found in the range of 0.3 s RT for the perception of speech in the classroom. Relatively longer RTs may prove potentially beneficial, but only in classrooms substantially larger than those addressed in this team's proposal. Teachers' vocal health in the classroom is essential. The best ways to protect vocal health while simultaneously addressing children's need to perceive speech require further investigation, and future code developments will need to reflect new insights. The increase in school constructions costs, even if every classroom was built with RT reduced from 0.6 s to 0.4 s, would likely add less than 1% to the cost of the construction of a school.

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