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Acoustic Ergonomics of School

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Akustische Ergonomie der Schule

Kurzreferat

Die aus Schulen und anderen Bildungsstätten laut gewordenen Klagen über starke Geräuschbelastung gaben Anlass dazu, die möglichen Ursachen und Folgen dieses „Schullärms“ genauer zu beleuchten. In der vorliegenden Studie zur „akustischen Ergonomie der Schule“ werden in diesem Zusammenhang am Beispiel zweier Grundschulen

Grundschule Stichnathstraße: 1.-4. Jahrgang, je 2 Klassen, mit unterschiedlichen raumakustischen Bedingungen (EG: RT > 0,5 s und OG: RT < 0,5 s)

Baumberge-Schule: 2. Klasse vor und nach der Sanierung der Raumakustik

die aktuellen pädagogischen Trends in ihren konkreten daraus resultierenden Arbeitsformen und dem damit verbundenen Kommunikationsverhalten im Unterricht beleuchtet. Auf der Basis von 175 Unterrichtsstunden werden in einem ersten Schritt dabei die Auswirkungen der verschiedenen Arbeitsformen (Frontalunterricht vs. differenzierter Unterricht) auf Grund- (L_{A95}) und Arbeitsgeräuschpegel (L_{Aeq}) im Klassenraum analysiert. In einem zweiten Schritt wird untersucht, wie sich eine veränderte Raumakustik (Nachhallzeit und Sprachverständlichkeit) auf diese Pegel im Kontext der jeweiligen Arbeitsform auswirkt. Die Ergebnisse liefern die Basis zur weitergehenden Frage nach dem Einfluss raumakustischer Bedingungen auf die physiologisch messbare Beanspruchung der Lehrerinnen und Lehrer in Abhängigkeit vom Unterrichtsgeschehen, Arbeitsformen und Redeanteilen. Die Analysen zeigen unter anderem:

1. Am Beispiel einer Sanierung kann eine Pegelreduzierung von bis zu 5 dB bei frontalem Unterricht und 12 dB bei differenzierten Arbeitsformen nachgewiesen werden, wovon 9 dB auf verändertes Schülerverhalten zurückzuführen sind.
2. Die physiologische Beanspruchung reduziert sich unter besseren raumakustischen Bedingungen im Mittel um 3 Herzschläge pro Minute, während auf die einzelne Person bezogen in vergleichbaren Situationen die Beanspruchung um bis zu 10 Herzschläge pro Minute sinkt, Ermüdungsprozesse werden geringer.

Insgesamt lässt sich belegen: Die Arbeitsbedingungen werden durch Verbesserung der Raumakustik positiv verändert, der Geräuschpegel sinkt, das Sozialverhalten der Schüler wird ruhiger, die Lehrkraft erlebt eine geringere Beanspruchung bei gesteigerter Aktivität bei gleichzeitiger geringerer Empfindlichkeit gegenüber dem Geräuschpegel.

Schlagwörter:
Schullärm, Raumakustik, Ergonomie, Sprachverständlichkeit, Lärmbelastung, Beanspruchung, Stress

Acoustic School Ergonomics

Abstract

The complaints about heavy noise pollution in educational institutions were the cause to cast a light on the possible causes and consequences of “school noise”. In this context the present study cast a light on the topical educational trends and the connected kind of work and communication behaviour in the classes by means of two elementary schools

Grundschule Stichnathstraße: 1. to 4. year, 2 classes per year with different room acoustic conditions (first floor: RT > 0,5 s and sond floor: RT < 0,5 s)

Baumberge-Schule: 2. year, before and after room acoustic redevelopment.

In the first place it is analysed how the different kinds of work (frontal lessons vs. differentiated lessons) have an effect on basically (L_{A95}) and working sound pressure level (L_{Aeq}) in the classroom, on the basis of 175 lessons. In the second place it is investigated how an altered room acoustic (reverberation time and speech intelligibility) has an effect on the sound levels in context with each kind of work. The results provide the basis for the further question which deals with the influence of room acoustic conditions on the teachers’ measurable physiological load depending on class events, kind of work and speaking parts. Among other things the analysis shows:

1. A reduction of sound pressure level up to 5 dB at frontal lessons and 12 dB at differentiated lessons (9 dB follow from changed student behaviour) can be proved on the example of redevelopment.
2. Under improved room acoustic conditions the physiological load decreases at 3 heart beats per minute in average. In comparable situations a single person’s load decreases up to 10 heart beats per minute, fatigue processes decrease too.

Altogether, with room acoustic improvement the work conditions improve, the sound level decreases, the students’ social behaviour becomes calmer, the teachers experience a lower load at increasing activity and at the same time a lower sensitivity with regard to the sound level.

Key words:
Noise in school, room acoustic, ergonomics, speech intelligibility, noise pollution, physiological load, stress

Ergonomie acoustique de l'école

Résumé

Les lamentations qui viennent des écoles et autres établissements scolaires concernants la pollution sonore ont donné lieu à demander des raisons et les conséquences de cette «pollution sonore dans l'école». Dans cette étude «d' ergonomie acoustique dans l'école» on examine par l'example de deux écoles primaire:

> Grundschule Stichnathstraße: 1er à 4ième classe, chaque fois 2 classes avec des conditions different acoustique (rez-de-chaussée: RT > 0,5 s et supérieur: RT < 0,5 s)
>
> Baumberge-Schule: 2ième classe avant et après l'assainissement de l'acoustique de la classe,

les tendances pédagogique actuel avec les façons de travail les suivantes et les rétentions de communication pendant les leçons. Sur la base de 175 leçons on analyse pendant un premier pas les effets des different façons de travail (leçons frontal et les façons de travail différentier) du niveau sonore de fond (L_{A95}) et du niveau sonore de travail (L_{Aeq}) dans la classe. Pendant un deuxième pas on analyse comment l'acoustique changée (la durée de réverbération et l'intelligibilité) se répercute sur ces niveaus en context des façons de travail different. Les résultats donnent la base à la question considérable de l'influence des conditions acoustique sur la demande physiologique mesurable pour les institutrices et les instituteurs à la dépendance d'événement de leçons, les façons de travail et les parts de conversation. Les analyses fait voir entre autres choses que:

1. À l'example d'un assainissement on peut prouver une réduction de la pollution sonore jusqu'au 5 dB avec les leçons frontal et jusqu'au 12 dB avec des manières du travail différentier. De cela on peut attribuer 9 dB à la rétention changé des élèves.
2. La demande physiologique se reduit sous une maniement mieux acoustique en moyenne vers 3 pulsations du cœur par minute, tandis que la demande se reduit à la même situation pour une personne jusqu'au 10 pulsations du cœur par minute, symptômes de lassitude se diminuer.

En tout on peut démontrer: les conditions du travail changent positif par l'amélioration de l'acoustique, la pollution sonore se réduit, la rétention social des élèves se calme, l'instituteur fait l'experience d'une demande réduite avec une activité élevé et une sensibilité plus bas pour le niveau sonore en même temps.

Mots clés:
Bruit dans les établissements scolaires, acoustique, ergonomie, intelligibilité, pollution sonore, demande, stress

1 Introduction

This work resides in the long tradition of the Institute of interdisciplinary school research (ISF) of the University of Bremen. During the ‘70s, the research group centred around J. BERNDT and H.G. SCHÖNWÄLDER undertook the task of drawing as complete a picture as possible of the events in our schools by means of a practical field research and the linking of different scientific disciplines (pedagogy, medicine, social and engineering sciences). From the beginning, the work centred on the "school as a workplace" and as such, the workplace of teachers and pupils.

The subject area of "noise in schools" as a diagnosable load value first became a focus of interest at the end of the ‘90s during the project "Belastung und Beanspruchung im Lehrerberuf " (Load and stress in the teaching profession) commissioned by Bremen's education senator. The results were sufficiently convincing to prompt the Federal Institute for Occupational Safety and Health to commission the ISF to carry out the follow-up project "Lärm in Bildungsstätten" (noise in educational institutions) – the largest field study to date on the subject of noise in schools in Germany. Noise level and corresponding room acoustic data was collected and basic teaching events (teaching, shares of speech, interference factors) were also recorded by participating observers in over 570 teaching units in 28 different school classes at 5 different schools.

A selection of this data, to which are added physiological heart rate records, forms the basis of the present work, which aims to take a further step in testing the relationship between room acoustic working conditions in the classroom, noise level in the pedagogical working process and the concurrent physiologically measurable working load of the teacher. The aim, as with the first studies of the ISF 30 years ago, is once again to produce as complete a description as possible of the reality of teaching.
The possibilities – but also the limits – of interdisciplinary research are also revealed in the present work. It is still not possible to take full account of all individual aspects of the relevant disciplines of pedagogy, occupational science and engineering sciences. Instead, the methodology offers an otherwise unattainable insight into the relationships across the boundaries of the respective specialist disciplines.

1.1 The school as a workplace

There is nothing new in viewing the school as a workplace both for pupils and for teachers. BURGERSTEIN AND NETOLITZKY (1902) took this concept into account in their "Handbuch der Schulhygiene" (manual of school hygiene), although this was repeatedly forgotten in the broader discussion. This approach only resurfaced in the context of the discussion of school-related stress in Germany towards the mid ‘70s of the last century. This term was applied to the workplace of the pupil in the research project "Belastung und Beanspruchung am Arbeitsplatz Schule" (load and stress in the school workplace) by BERNDT ET AL. (1976, 1977, 1979) and SCHÖNWÄLDER (1977). RUTENFRANZ'S contemporary work adopts the same approach (1977). The "Belastungs-Beanspruchungs-Modell" (load-stress model) from occupational science

introduced by ROHMERT AND RUTENFRANZ (1975) appears here for the first time with respect to pupil activities. A general form of the model is illustrated in Figure 1.1.

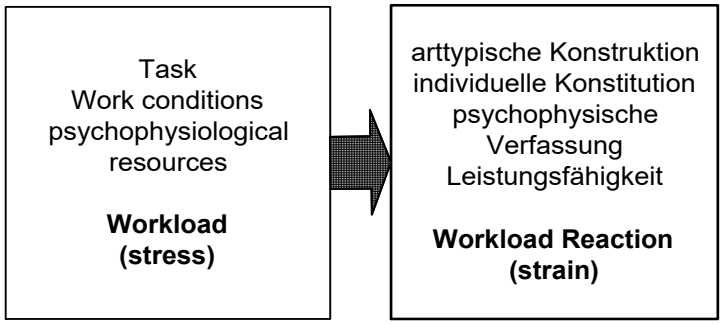


Fig. 1.1 Stress-strain model according to BERNDT ET AL. (1976)

A much more detailed illustration of this model can be found in Rohmert and Rutenfranz (1983). The authors have adapted this model to the school workplace as illustrated in Figure 1.2.

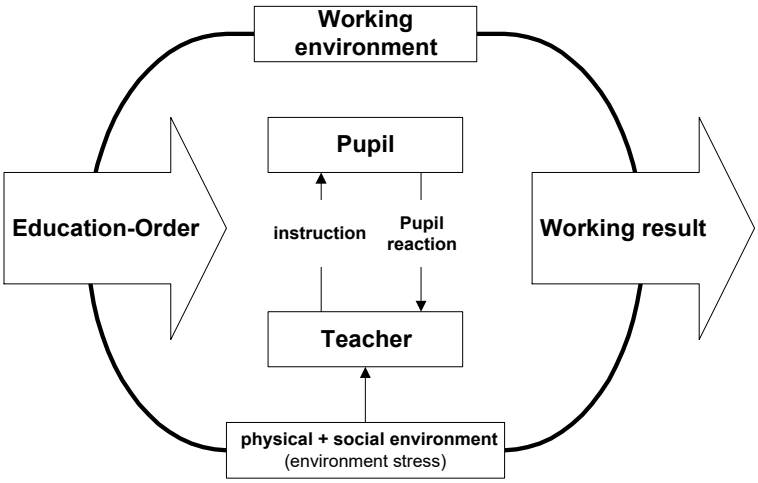


Fig. 1.2 "School" work system modified according to ROHMERT AND RUTENFRANZ (1983)

In this model, the focus is on the interaction between teacher and pupils, in other words the task itself, but also the influence of the working environment on this work process. The nature of the "teaching task" and the "work product" are rarely questioned.
The working environment or the ergonomics of the workplace has a central function within this model. For industrial workplaces, for which this model was originally developed, SCHMITDKE (1993) lists the following factors:

- climate
- radiation
- pollutants
- mechanical vibrations
- workplace design (working posture)
- lighting
- noise

Naturally these factors should be taken into consideration when planning a school building. There are numerous investigations from the field of occupational science into the issue of *climate* with varying focal points. Proposals for the design of workplaces can be found, e.g. in SCHMITDKE (1974). Specifications are defined in the German workplace directive of 1996. It can be assumed at least that school buildings in Germany do not generally have central air-conditioning or ventilating systems and that the room climate is manually controlled. This much can be understood from the Hamburg health authority's "Empfehlungen zum Lüften von Klassenräumen" (recommendations for the ventilation of classrooms). The factors of *radiation, pollutants* and *vibrations* can usually be considered as irrelevant in classrooms. The only pollution problem has been due to the use of polluting building materials. One tends to think particularly of asbestos and PCBs. On the other hand, workplace design in relation to the *seating or working position* is of particular significance in schools due to the physical development phase of school-age pupils . The basis for this can also be found in BURGERSTEIN AND NETOLITZKY (1902) and applies as much today as then, as does the factor of *lighting*, for which we have far better solutions than 100 years ago. When BURGERSTEIN AND NETOLITZKY mention the *noise* factor, while it is referred to as being at the workplace itself in terms of occupational science, in relation to schools the only noise perceived at that time was that carried from outside into the building; environmental noise and primarily traffic noise. The "noise" generated by the work process itself, referred to more precisely as work noise, is disregarded as are the basic acoustic conditions of the room.

SOBOTKA (1977) describes the schoolroom climate as a being a design problem since it is a "Voraussetzung for Wohlbefinden and Leistungsfähigkeit" (precondition for well being and efficiency). She describes correct ergonomics as being essential for fulfilment of the brief. Noise level, however, is not included in her list of room climate factors. A much more recent study by SCHNEIDER (2002) precisely one hundred years after BURGERSTEIN continues to ask: "Do School Facilities Affect Academic Outcomes?" and attempts to produce an overall relationship between the ergonomic conditions in schools and the results of pedagogical efforts. Relationships were found, at least for the conditions investigated at schools in the USA. However it is not possible to link the relationships to individual factors

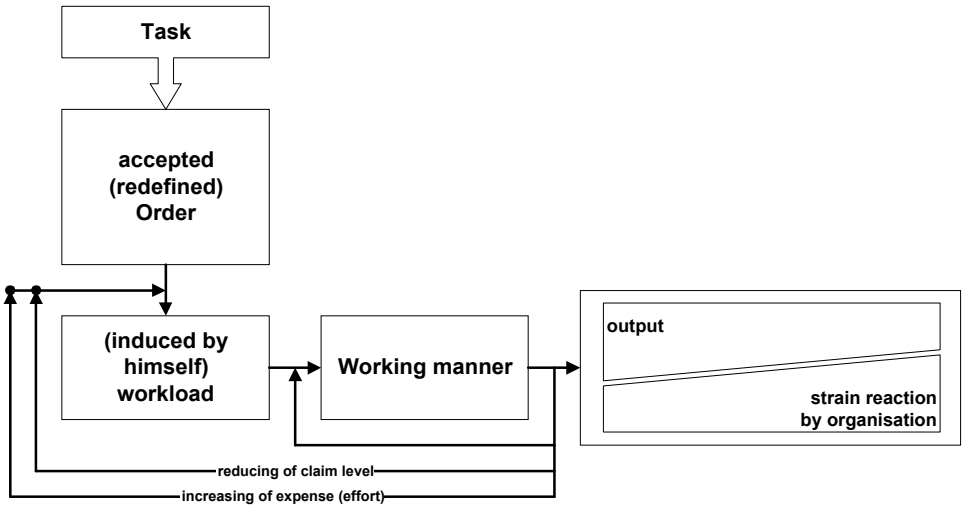


Fig. 1.3 Task-analysis concept according to RICHTER AND HACKER

Ultimately it is not the pupils but the teachers who form the focus of the present work, albeit in the process of working with their pupils. With regard to teachers' perceptions of their work situation, one factor emerges as being particularly significant, at least from the perspective of stress management. For this reason RICHTER AND HACKER introduce an expanded version of the original load-stress model and describe this as the "Auftrags-Auseinandersetzungs-Konzept" (Task-analysis concept) illustrated in Figure 1.3.

Two terms are introduced here which have great significance for the management of the task. The first is the redefinition of the task with the second being the self-imposed stress. In accordance with the load-stress concept the term *self-imposed stress* ought to be *self-imposed load* since this is the cause of the resulting stress. The factors of feedback of the working method, self-imposed stress and redefinition of the task are still of particular significance in relation to the stress management.

1.2 Pedagogical trends

One should not overlook the fact that the education system in Germany is in an unprecedented state of transition and not just since PISA or TIMSS. Numerous German states (with varying consequences) are facing or have already carried out educational reforms. Core curricula, educational standards, centralised final examinations, the introduction of the "school TÜVs", the shortened secondary school period or the increase in all-day schools are just a few external indications of organisational changes which are accompanied by constant and intensive comparison with other European countries and not least a vigorous internal competition amongst individual German states.

However, changes to the external school organisation are not the real milestone. The changed working methods being adopted within the external framework are proving to be of far greater interest. The resulting wide-ranging debate about pedagogical trends and procedures in the German educational system cannot be covered in detail by the interdisciplinary approach adopted in this study. However, see for example WINTER (2002), which provides a good overview of the current "zwar uneinheitliche, aber breite Suchbewegung nach erweiterten Lehr- und Lernformen in der Schule" (non-uniform, but nevertheless extended search for expanded teaching and learning methods at school). He identifies the fact that it is "nicht lediglich um die Reform" (not only related to the reform) of individual teaching methods but about the attempt "den Unterricht, das Lehren und Lernen, in einen neu definierten Zusammenhang zu bringen" (the attempt to bring teaching and learning into a redefined context) and sets out, in accordance with WEINERT (1977), three fundamental features of this new learning culture: openness, independence and individuality.

Openness
The criterion of openness does not relate exclusively to working and teaching methods, which normally include "open-ended teaching" such as project work, weekly-plan work, pupil-directed work or workstation-based learning in which learners exercise more self-determination than normal when it comes to their time and sometimes over the choice of subject matter. It also includes a changed distribution of the roles of the learner and teacher which WINTER calls "institutional openness".

This openness in no way means that teaching is "ungeplant oder ohne Bestimmung von Zielen abläuft" (unplanned or without goals). On the contrary, this kind of open teaching demands very careful planning and a high degree of competence in control and structuring from the teacher. It forces teachers to expand their areas of activity and their repertoires of behaviour. Learning agreements with the pupils are required and the accompanying evaluation, reflection and (possibly joint) re-conception of the task become fundamental elements of the interaction.

Independence
The aim, and equally the basis for this openness, is that pupils more often work and learn independently in this form of learning culture. "Autonomy" is the key word. Amongst other things, autonomy is necessary for the lifelong learning which itself is necessary in order for people to deal with their personal and economic futures. Concepts of this new learning culture, according to WINTER, are therefore "deutlich auf die Schülerseite orientiert und achten darauf, dass diese ihre Handlungen selbst steuern und kontrollieren" (Clearly orientated towards the pupil and are aimed at ensuring that they take responsibility for their own actions).

Individuality
A consequence of these two features is greater individuality in learning. Pupils can and should "– zumindest phasen weise – auf ‘eigenen Wegen‘ lernen" (- at least part of the time – learn in their own way).
In the current educational debate, however, this is accompanied by a focused shift in the description of the teacher's work. Teacher's specialist knowledge is becoming less important while operative skills are increasingly important for appraising and guiding processes. WINTER cites the key qualifications as being methodological competence, social competence and self-awareness and/or interpersonal competence.
As a result of these basic changes in direction the pedagogical debate is responding amongst other things to dramatically changed conditions under which teaching must now be carried out. For KLIPPERT (2002) independent working and learning are the most important components of a "neue Haus des Lernens" (new house of learning) and they are the answer to changed pupils, to new challenges to schools and to a growing teacher workload (Fig. 1.4).

The traditional methodological repertoire, according to KLIPPERT has for a long time "längst nicht mehr aus, um den veränderten Lerndispositionen und –interessen dieser Schülerinnen und Schüler gerecht zu werden" (long been inadequate to the task of meeting the changed learning disposition and interests of these pupils). He therefore also demands an urgent "grundlegende Veränderung sowohl des Rollenverständnisses als auch des Methodenrepertoires der Lehrkräfte". (A fundamental change in both the understanding of the role and the methodological repertoire of the teachers).

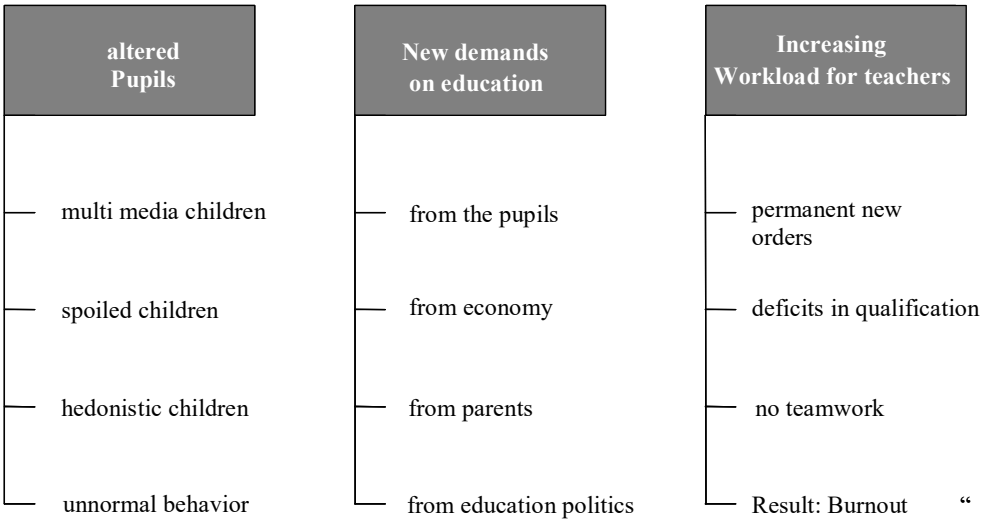


Fig. 1.4 Changed basic conditions in schools according to KLIPPERT (2002)

He draws on neurological research and learning phsychology for support. STRUCK (2001) reports on a investigation model in which children learned "in zwei Fünftel der bisherigen Zeit etwa dreimal so viel" (three times as much in two fifths of the previous time) and "das Gelernte etwa dreimal so lange im Gedächtnis parat hatten" (retained what they had learnt for three times as long), when they were able to determine tempo, breaks, depth and answers and/or transfer themselves. The children learnt more vigorously and with more motivation and were more active than in "herkömmlichen direkt vorgehenden lehrerzentrierten Unterricht der Wort- Buch- und Zettelschule" (conventional, direct teacher–centred chalk and talk methods). STRUCK formulated eight learning-psychology principles (cited according to STRUCK):

1) Children and adults learn less when someone teaches them and learn better when they learn by themselves.
2) Young people learn better when they can learn and do at the same time ("Learning by Doing").
3) Pupils learn better when they are allowed to make mistakes without being criticised.
4) Children learn better from people their own age than from adults.
5) Children learn best when they have to explain to others what they have learnt. Good learning goes hand in hand with speaking.
6) Good learning requires positive, helpful, and encouraging feedback.
7) Children learn best when they have to solve a problem in pairs.
8) Children in same-age groups probably do not learn as well as in mixed-age classes.

Along with this, however, the basic direction of a reasonably modern teaching approach is determined in relation to the postulated "neuen Lernkultur" (new learning culture): the teacher is perceived less and less as a distributor of material or a conduit for preconceived knowledge. This also means changes to the activities in the classroom: Pupils need to experiment, assess and discuss with one another. Morning meetings, discussion groups and role play locates the cited learning psychology approaches firmly in the everyday teaching events. Rather than sitting alone in front

of a problem (set as class work or for homework) or as just a part of the class society, learning increasingly has to take place communally. Working with a partner, claims Struck, is the most efficient form of learning. It is „der Kleingruppenarbeit, diese in der Regel der Einzelarbeit und durchweg dem Lernen in großen Gruppen überlegen“ (it is generally better than working in small groups and definitely better that working in larger groups). Teacher activities are also changing. Their role involves far more observation, enquiring and moderation. The delivery of material is of less importance than it used to be.
From time to time the current educational debate draws an exaggerated picture which shows traditional direct teaching as being out of date, no longer in keeping with the times. On the basis of the above it is actually hard to imagine how pupils will achieve the qualifications they need with these learning methods. However, it is clear that direct teaching, if one is to believe the investigations of Gudjons for instance, is still the most frequently practiced form of teaching in German classrooms. Gudjons (2000) defines modern direct teaching as "mostly thematically orientated and linguistically disseminated form of teaching, in which teachers are jointly instructed and in which the mostly direct interaction and communication forms can be controlled by the teacher”. This takes place within relatively specific boundaries. Direct teaching is therefore a didactically sensible form of teaching if the objective is to communicate a clearly delineated area of knowledge quickly and efficiently. Provided pupils are not required to be involved in cooperative problem-solving, direct teaching, according to Gudjons (2000) is a "a very effective form of teaching because the teacher can plan everything very precisely in advance [...]. Direct teaching requires less time for the distribution of facts and is more effective because it is more economical of time“. He came to the further conclusion in his investigations that direct teaching is relatively popular with pupils, provided the teacher exudes a positive, lively and emotive personality, and teaching takes place within a framework which encourages discussion.
GUDJONS cites several basic functions which are most efficiently fulfilled by direct teaching. Along with information and networking (for instance, to bring all pupils to the same level of knowledge), assuring results and checking learning success are primary examples of these functions. However, even with direct teaching, immediate and direct feedback is necessary. There is no place for static teaching or lecturing! "Direct" communication is not a one-way street from the blackboard to the pupils.

One might therefore expect that direct teaching is unlikely to disappear from the repertoire of our schools in the near future (although such schools do exist according to SCHÖNWÄLDER ET AL., 2004). Another assurance is that it provides teachers with a very economical method of working with comparatively little preparation. Perhaps GUDJONS (2004) is also right in his assumption that direct teaching is not least an essential building block for functional open teaching methods if only to prepare and organise the class for what is to come. He holds to his justification of direct teaching as a didactically sensible form of teaching "wenn a) ihre spezifischen Vorteile und eben ihre Grenzen deutlich erkannt werden und b) wenn Frontalunterricht in Verbindung mit anderen schülerorientierten und Selbstständigkeit fördernden Verfahren steht; c) kann man noch sagen, Frontalunterricht ist dann sinnvoll, wenn er gut gemacht wird: spannend, modern – einfach professionell". (if a) its specific benefits and its limits are clearly recognised and b) if direct teaching is used in conjunction with other processes which are more pupil-orientated and conducive to self-responsibility; c) one can say also that direct teaching makes sense when it is well-done: exciting, modern – professional in other words.)

These, then, are the key issues in the current debate. This is not the place for an intensive critique of the discussion. It is worth noting, however, that many the terms that one reads even during a cursory glance at the literature are not as "new" as they might seem. And according to occupational science standards the chain of argument in the pedagogical literature is not always as stringent and well founded as one would like. An interdisciplinary communication problem? At the very least there is a need for a reference to a reliable parameter for measuring the oft-cited "efficiency".

In summary we can be certain that both in the case of the much mentioned and discussed pupil-centred teaching methods, but also in the case of traditional direct teaching in its modern garb, the classroom is a stage for a fundamentally changed communication scenario. As one of their most important tools, it must be possible to measure basic conditions available to the teacher against this changed way of working.

1.3 "Noise in schools"

It does not seem unsurprising to talk of occupational noise in the context of schools and/or vocational educational establishments. In this context, the discussion has never addressed harmful occupational noise exposure. The suspicion that the average level of 80 dB (A) is exceeded so often in educational establishments that affected persons might develop occupational noise-related hearing impairment has also been rarely expressed. This information was first presented by RITTERSTAEDT, PAULSEN AND KASKA (1980). They measured noise levels of between 50 dB (A) and 80 dB(A) during lessons and breaks in primary and secondary schools within the state education system. However, readings above 85 dB (A) did not occur regularly, even during peak value measurements. In an investigation by ENMARKER AND BOMAN (2004) pupils were questioned about the possible causes of noise in school. Various explanations were given. On the one hand school organisation was cited as a reason, e.g. class size, duration of lessons and inadequate teacher presence, while all noise produced by others, e.g. other pupils' conversations or noise from the corridors was another. Pupils rarely perceived their own contribution to the noise level.

From an investigation by SCHÖNWÄLDER ET AL. (2003) on load and stress in the teaching profession one finds that "... der Lärm, den Schülerinnen und Schüler machen" (the noise that pupils make" was cited by 80 % of over 1,200 teachers questioned as a particular stress factor. The same study also reports on dosimetric noise level measurements - carried out as a result of the above claim - for nine primary school teachers over whole school days. The average level observed for lessons was between 63 and 85 dB(A). These values naturally do not comprise "noise", because for instance and the teacher's voice and desired pupil's voice are wanted signals yet they are included in the measurement (see below). Nevertheless, even if this noise level were exclusively caused by the teacher this would at least mean that s/he had had to speak in a raised voice all the time. A similar picture emerged at a second primary school in which stationary noise level measurements were carried out over a week in each year-four class. Here the average levels for the lessons were between 57 and 73 dB(A). Also since these noise level levels mainly fall within the intensity range below 85 dB(A), it can be assumed that neither pupils

nor teachers run the risk of incurring inner ear damage from the mutually created noise level in the classroom.
One exception to these observations are the investigations of HÄNTZSCHEL (1980) who concerned himself exclusively with noise in sports halls. He found average noise levels of between 82 and 85 dB(A) for a morning of five lessons including breaks with up to 92 dB(A) for individual lessons and peak values between 100 and 110 dB(A). SCHÖNWÄLDER ET AL. (2003) reported similar noise levels for sports lessons. In sports halls equipped with acoustic baffles, the levels for an equivalent morning were 76 dB(A) with peak values of below 95 dB(A). The halls without baffles featured reverberation times of between 2.6 and 4.5 sec and less than 2.0 sec for those with baffles.

Nevertheless it is clear that in "normal" teaching the problem of "noise in schools" cannot be described in terms of its risk with regard to aural impairment. The important issue is far more the effect of "less loud" or "less intensive" noise in the workplace of teachers and pupils. In this context SCHÖNWÄLDER (1990) defines teaching as a "Produkt gemeinsamer Arbeit von Lehrer und Schülern" (product of the joint work of teacher and pupils). It is therefore equally clear that teaching is a process in which, although it is controlled by one person, the subsequent process reaction relies on interaction. The standard value on which the process of an occupational science observation is based need not be discussed further here. It is in any case based on the task.

A key control instrument is the "speech" of the teacher which has led in the past to many investigations e.g. of the percentages of teacher speaking time during lessons. In his illustration SCHÖNWÄLDER (1990) speaks of an unchanged "Sprachdominanz" (speech dominance) of the teacher, i.e., the percentages of teacher generated speech in lessons are higher than the percentages of pupil generated speech. Teacher generated speech is therefore of particular significance in the development of the noise level in lessons (see above). Nevertheless, in relation to the distance between the speaker and the listener the noise level of human speech lies within the range between "Flüstern" (whispering) (40 dB(A) and "lauter Schreien" (loud shouting) (85 dB(A) (according to SILBERNAGEL AND DESPOPOULOS, 1991). According to RITTERSTAEDT, PAULSEN AND KASKA (1980) speech occupies 66 % of the overall lesson period while other noise sources occupy 65 %. General noise dominates 17 % of lessons and impermissible noise amounts to 20 %. The authors define the noise level parameter L_{A95}. In other words the level that is exceeded for 95 % of the time becomes the "Grundgeräuschpegel" (basic SPL) in the class room. There has been no reliable temporal data relating to the distribution of individual speech percentages in lessons – particularly in the context of different pedagogical working methods. In all future investigations, this aspect of teaching communication in particular requires more consideration than it has previously received.

In this context one ought to mention an area of environmental noise which is not immediately related to "noise in schools" (at least in the context of this investigative approach): any noise to which most people more or less voluntarily expose themselves, the noise level which is produced by any type of (music) consumption. KLEMM (1993) describes the "Schule der Stille" (silence is golden) as an old concept that needs to be revived. She documents the changes in the living environment of children and in the background of noise against which we live our lives and the affects associated with our increasingly thoughtless interaction with noise. She

derives a series of requirements for pedagogical behaviour in order to counteract this development as far as possible. ZENNER ET AL. (2000) also complain in their study about the heedless involvement of young people with dangerous situations citing several examples: shooting sports, children's toys, music, discotheques, headphones (Walkman) and large music events. They differentiate between temporary hearing loss of a few hours to several days, and permanent hearing loss, which has been diagnosed in young people of between 14 and 20 years, and report on a series of investigations with 18-year old conscripts in which the percentage of the sample with hearing loss in the C5-range > 20 dB(A) was 15 % bilateral and over 35 % unilateral.

One might speculate over the relationship between this type of environmental noise as a reason for undetected hearing loss in children and a resulting need for higher noise levels. This modern recreational and environmental noise might ultimately infiltrate the events in the classroom via this a kind of "vicious circle". The authors are unaware, however, of any reliable investigations in this area. Only an investigation by LEICHT (2003) from Australia concerns itself with the question of the effects of hearing impairment on learning and behaviour. She reports on frequently occurring middle ear infections in childhood accompanied by temporary reduced hearing capacity and its effects on speech and writing development as well as on behaviour.

1.4 Definitions of noise

"Der Lärm ist die impertinenteste aller Unterbrechungen, da er sogar unsere eigenen Gedanken unterbricht, ja zerbricht ..." (noise is the most impertinent of all interruptions because it interrupts, even shatters, our very thoughts...)
(Ascribed to Arthur Schopenhauer, 1788 - 1860)

Sounds of differing quality and intensity occur in all areas of human society. Typical primary sources of noise are occupational activities of the most varied types and communication between people in all its manifestations. The number of people who feel burdened by noise and who feel that it affects their quality of life is rising constantly.
But what is noise? How does it differ from other sounds? To be able to address the question of noise load, particularly the differing points of view, it is necessary to discuss three definitions representing different points of view.

Definition 1:
"Noise which occurs in the working environment and whose frequencies are perceived by people (heard noise)" (CHRIST 1997)
This definition describes all heard sound as noise, which clearly goes against the general perception. The very broad definition is derived, according to the author, from the first workplaces addressed by occupational science, i.e. the metal industry, in which for the first time it was possible to obtain very reliable proof of aural damage due to noise load. CHRIST also outlines this definition further in the subsequent explanation. This formulation is clearly not applicable to the school workplace, in which communication is at the forefront of activities.

Definition 2:

"… more or less intensive noises produced by irregular, non-periodic acoustic wave forms, which contain no useful information for the receiver and which are generally perceived as interference." (FRÖHLICH 1994)
This definition of the term noise by FRÖHLICH (1994) includes two essential elements for communication, information and interference. This primarily concerns the subjective interference with hearing perception and/or feelings. What further effects this might possibly have are of no interest. This definition is concerned only with a momentary situation.

Definition 3:
"Noise is an unwanted sound that poses a load, interference, distraction from performance potential, a particular risk of accident or is damaging to health" (HOFFMANN, VON LÜPKE, MAUE, 1999)
This third definition by HOFFMANN, V. LÜPKE, MAUE (1999) provides a further dimension, the long term effect on several levels, firstly performance and secondly the possibility of the risk of accident and long term possible health damage of an aural and extra-aural type. This linking of pure interference by a sound with the possibility of longer-term interference, even so far as health damage, is also emphasised by GUSKI (2000) in his definition. It will be necessary to return to the significance of noise for occupational performance, which essentially comprises cognitive processes in relation to schools and education. It is of course foreshadowed by the quote from Schopenhauer.

Thanks to the efforts of occupational medicine with the support of the state legislature in Germany (UVV Lärm [accident prevention directives on noise]) it has been possible in particular to greatly reduce the occurrence of noise-related hearing impairment caused by noise levels over 85 dB (A). The effects of this "loud noise" on the human hearing organs (noise-related aural damage), particularly of the inner ear with its sensitive hair follicles, in the form of temporary or permanent hearing impairment are investigated with the utmost accuracy in this context (ISING AND KRUPPA, 1993). As well as these aural effects of noise, however, research is now focusing attention increasingly on the extraaural effects, i.e. on all those symptoms which do not relate to hearing itself but above all to the cardiovascular system and also to physical well-being. Examples are documented in the conference report no. 12 (Lärm am Arbeitsplatz und Herz-Kreislauf-Erkrankungen (Noise at the workplace and cardiovascular diseases) from the Bundesanstalt für Arbeitsmedizin (Federal Institute for Occupational Safety and Health) (1996). The triggering of acute stress reactions by noise, in this case however essentially "loud noise" over 85 dB (A), is undisputed and has been confirmed by a series of investigations. On the other hand, while the long-term influence of "quiet noise" (< 85 dB (A)) on the development of cardiovascular disease is not doubted, there is no clear proof yet. This possibly relates to the proof of noise exposure in the past. In addition, the subjective claims of affected persons when evaluating sound events as noise is often inaccurate with regard to both the intensity and the duration if the noise is interpreted and "experienced" according to FRÖHLICH (1994). For example, a motorway will generally be evaluated very differently when compared to a performance in a concert hall even if the two are objectively similarly loud. The standard is predominantly ones own subjective attitude to the sound.
The answers to the question regarding the annoyance caused by pupil noise in the study by SCHÖNWÄLDER ET AL. (2003) about load in the teaching profession are subject to the same subjective problems. In a direct comparison with the perceived

annoyance caused by pupil noise at the start of their professional activities at the time of the survey, almost 90 % of those asked noticed a considerably increased sensitivity to noise during their professional lives. This may indicate a decreased tolerance to noise when one is regularly exposed to that sound at the workplace over a long period (years). This would contradict the general assumption that one becomes accustomed to noise.
As apposed to "loud noise" for which traditional occupational science gives a clear definition concerning the average level, it is less simple to evaluate the quality of the interference caused by "quiet noise". On behalf of the Bundesanstalt für Arbeitsschutz and Arbeitsmedizin (Federal Institute for Occupational Safety and Health) PROBST (2003) produced a definition in accordance with VDI 2569 "Schallschutz und akustische Gestaltung im Büro" (sound protection and acoustic design in the office) and VDI 2058 sheet 3 "Beurteilung von Lärm am Arbeitsplatz unter Berücksichtigung unterschiedlicher Tätigkeiten" (appraising noise at the workplace taking into account varying activities) for office work areas based on the noise level levels illustrated in Table 1.1.

Table 1.1 Recommended technical noise limits for monitor workstations according to PROBST (2003)

Noise level range (average level at workstations)	**Recommended technical noise limit, workstation**
Up to 30 dB(A)	Optimum
Over 30 dB(A) up to 40 dB(A)	Very good
Over 40 dB(A) to 45 dB(A)	Good
Over 45 dB(A) to 50 dB(A)	Acceptable in a commercial environment
Over 50 dB(A) to 55 dB(A)	Not favourable but still permissible
Over 55 dB(A)	Noise load too high

PROBST goes on to specify criteria with regard to the ability to identify individual sound sources and for speech intelligibility between different occupational areas (private sphere). He formulates the requirement " as low as possible” with regard to the overall noise load.
This portfolio of noise definitions for different commercial spheres of activity reveals the need to work out practicable criteria for schools with their predominantly communicative working modes.

2 Question formulation

2.1 Noise load and room acoustics

2.1.1 The effects of noise of average intensity

While one can assume the simple relationship with regard to the aural effects of noise: *" a lot of sound energy (intensity and duration) is damaging a lot"*, determining its extraaural effects is very much more complex. No such linear relationship applies in this case, at least to date no such simple effect equation has been proven. If one assumes that even noises of less intensity are stress inducing, one needs to answer the question as to what the possible effect mechanisms are. Within this context SUST AND LAZARUS (1997) list annoyance and interference with activities, mental processes, communication and restorative phases. Once again the focus is on the aspect of spoken communication as an essential part of education and further development. The communication objectives are widely varied. Social skills play an important role along with the delivery of information. SUST AND LAZARUS describe a major extraaural effect of noise – including and more specifically of quiet noise - as being disturbing to this communication process on three levels:

- Content is perceived incompletely, incorrectly or not at all
- Relational and self-statements are misinterpreted
- Behaviour requirements are perceived incompletely, incorrectly or not at all

One can add the aspect of the frequency of the annoyance to the dose effect principle in which the complexity of the task plays a decisive role. According to ISING, SUST AND REBENTISCH (1996) the potential of noise to be interfering increases:

- the more information to be remembered
- the more mental operations need to be performed (conclusions, mathematical operations)
- the greater the demand for continuous concentration and attention
- the more responsible the activities with regard to the consequences of failure (quality awareness)
- the more time pressure there is for completion of the task

In short, it is possible to derive a new causal-effect relationship from the above:

"The more complex the task, the more interference will be caused by noise"

Thus another interference quality can be attributed to noise. It no longer takes place just on a physical level but also in the region of cognitive functions. A further quality of interference on the physiological level is considered separately in section 2.3.

Using this kind of definition of the effects of noise it is now also possible to get closer to what happens during teaching. Since the work process in educational establishments essentially comprises communication between teachers and pupils (see section 1.3), the basic SPL above which the communication must take place is clearly identifiable as a major interference value – ranging beyond the purely physical relationships of, e.g. the signal-to-noise ratio (SNR) (see below). The speech volume

itself as an actual signal does not fall into the category of noise load, at least not for the speaker. From the speaker's perspective it is more the effort in speech required to make him/herself heard.

It is therefore necessary to find a means of differentiating useful noise from interference noise in order to evaluate the "noise load“ in schools. This is a primary task in the context of the predominantly communicative events in lessons. However, the noise levels measured during lessons in a classroom, for example the dosimetric measurements presented in section 1.3, so far say nothing about the intensity of the percentage of the amount of interference noise these might include. It is comparatively simple to determine the level of noise-interference, however, by measuring the basic noise when the classroom is empty. This therefore depends mainly on the location of the building, the structural quality of the soundproofing with respect to outside noise (traffic and environmental noise) or other parts of the building (incl. the carrying of the sound of footsteps) or of the technical equipment in the building (heating, air conditioning). In this context, early investigations by ESSMANN (1973) revealed wide variation with values from 40 to 55 dB(A) in empty classrooms with closed windows. In averagely loud classrooms the background noises were essentially the sounds of traffic transmitted from outside. In their study, which involved investigations of a total of almost 70 classrooms, MACKENZIE AND AIREY (1999) also reported an average background noise level in the empty classrooms of 44 dB(A). However, this should not be confused with the basic SPL during lessons. The average measured values of 55 dB(A) in the rooms occupied by all pupils (while the pupils were supposed to be working "silently" at their desks) were considerably higher than this "technical" background noise. By means of acoustic refurbishment of some classrooms (reduction of the reverberation time, see section 2.1.2) MACKENZIE AND AIREY verified the dependency of both noise levels on the basic acoustic conditions in the classrooms. The level reductions achieved by the refurbishment were considerably higher (Δl 9dB) during the children's working phases than in the empty classroom (Δl 4dB). The changed environment therefore also affected the noise emissions of the pupils during their working phases. This result supports current observations, e.g. from ORTSCHEID AND WENDE (2004), that even minor changes in noise level of 3 dB are perceived, contrary to previous assumptions. However, there has as yet been no detailed analysis of the relationships between basic room acoustic conditions and working behaviour in schools, particularly against the background of the different teaching in teaching.

SCHÖNWÄLDER ET AL. (2004) used a somewhat different method for identifying the basic SPL during lessons. They take the quietest 10 seconds of every lesson in a classroom and define this value as the background noise level in a "working classroom". They recorded values between 32 dB(A) and 52 dB(A) in relation to school and room layout.
Along with the background noise level, speech intelligibility in the classroom is particularly significant for the evaluation of its acoustic quality. The first decisive value is the difference in sound intensity between the desired and the interfering noise ("signal-to-noise difference"; signal-to-noise ratio; SNR). The literature offers very differing recommendations in this area. While DIN EN ISO 9921-1 considers a SNR of 7.5 dB as adequate for adults, SUST AND LAZARUS (2003) propose a SNR > 13 dB (Table 2.1) as the basis for "very good", i.e. largely error-free speech intelligibility. Their results are based on the investigations of speech intelligibility and on the basis of single syllables as well as whole sentences under laboratory conditions.

Table 2.1 Application of the quality scale to the speech transmission index (STI) and signal-to-noise ratios (SNR) on the basis of ISO 9921 and the results of SUST AND LAZARUS (2003)

Evaluation	ISO 9921		Sust & Lazarus	
	STI	SNR in dB	STI	SNR in dB
excellent	> 0.75	> 7.5	> 0.95	> 13
good	0.6 to 0.75	3 to 7.5	0.7 to 0.95	6 to 13
fair	0.45 to 0.6	-1.5 to 3	0.5 to 0.7	0 to 6
poor	0.32 to 0.45	-6 to –1.5	0.3 to 0.5	-6 to 0
bad	< 0.32	< -6	< 0.3	< -6

ROHMERT AND RUTENFRANZ (1983) also note that good speech intelligibility only exists when the speech volume is some 10 dB higher than the background noise level, with the qualification that the speech volume should be 20 dB higher than the basic SPL for difficult and foreign language texts. However, these values apply only to adults. SPRENG (2003) refers to the generally less efficient speech perception of children and NEUMANN AND HOCHBERG confirm a required increase of the SNR in the order of magnitude of 5 dB as compared to adults for children of primary school age (9 years). The WHO also states a SNR of 15 to 18 dB (FRANCOIS AND VALLET) as a condition for "very good" speech intelligibility in schoolchildren.

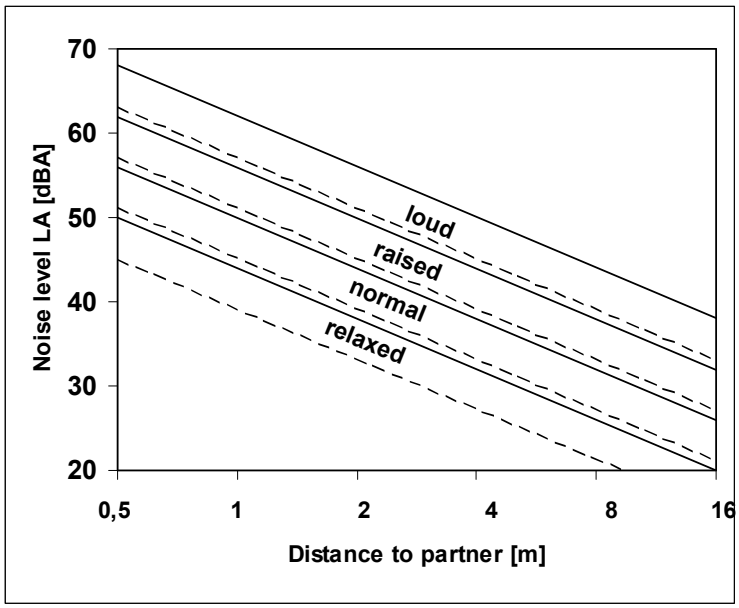


Fig. 2.1 Admissible interference noise level in order to achieve a very good (- -) and/or good (--) speech intelligibility in relation to the distance from the speaker – listener and the speech effort (according to ISO 9921-1)

In practice, there is a relationship, as illustrated in Figure 2.1, between the interference noise level and the distance from the listener and/or speaker in relation

to the speech effort and the speech intelligibility to be achieved (revised according to ISO 9921-1).

In accordance with the above diagram and based on this relationship, a standard classroom of 8 x 8 m and a distance between teacher and pupils of approx. maximum 6 m requires a maximum admissible basic SPL of 35 dB(A), normal speech volume and very good speech intelligibility. When one takes into consideration the stricter guideline values for the SNR proposed by SUST AND LAZARUS (2003) or the particular needs of growing children, one would tend to impose even stricter requirements.
JOACHIM (2004) also points out this problem in a note in which he proposes that background noise level in classrooms be limited to a maximum 30-40 dB(A) in accordance with EN ISO 11690-1.
When one considers this in the light of the communication processes in the classroom it also becomes clear that in practice these requirements are not primarily directed at the technical background noise level in an empty classroom. The deciding factor is the noise environment in which pupils work, in other words the background of noise generated by the sounds of working and the conversations of classmates. This aspect becomes more significant, particularly in the context of the open teaching of the "modern“, pupil centered teaching (see section 1.2). Pupils in particular do not produce the kind of uniform blanket of noise created, for example, by adults in open plan offices. And since partner- or group discussions always contain more or less short pauses for thought between the individual contributions, even a single intelligable word from a neighbouring group can interrupt the logical thought process (see again Schopenhauer, section 1.4).

This relationship is therefore particularly important because children of primary school- or secondary level I-age are by no means experienced listeners. Since our acoustic memory is not fully formed until the age of 12 years, understanding the spoken word is always associated with an increased hearing effort. SPRENG (2003) distinguishes between several phases of speech development, of which only those relevant to primary school children are referred to here. Firstly he mentions the "sensitive child phase" (4 to 6 years) and the "school child phase" (6 to 14 years). He describes the first phase as sensitive because key motor skills and particularly speech mechanisms develop in this period. Of central significance is the simultaneous processing of acoustic information as regards analysing its content, i.e. accessing memory structures in order to recognise "acoustic sequences“. The continuous influx of information constantly conceals or deletes earlier information. The more extensive the acoustic memory the easier it is to identify information immediately and therefore recognise the meaning. When new information is received, represented here by an acoustic pattern, this pattern must be stored in the memory. The process of storage in the long-term memory is however far slower than recalling information and is more easily disturbed, the more information that needs to be processed. One everyday example of this is remembering a telephone number by repeating it silently to oneself. The second phase of development according to SPRENG (2003) primarily depends on the creation of a relationship between hearing and speaking on one hand and between reading and writing on the other. It is also necessary to develop increased perceptive capabilities and to exploit speech redundancy and grammatical rules in order to ensure speech recognition when speech quality is poor or in the presence of noise-interference. Association centres play key roles, especially in dividing ones attention, for both learning as well as for

performing such complex cognitive processes such as speech comprehension, speaking and reading. We shall return to this again in conjunction with stress processes (see section 2.3).
Therefore if SUST AND LAZARUS (2002) have determined clear noise-related performance-interference even in adults, how much more must this apply to the working world of children who still need to learn these communication skills? An investigation based on the example of monitor workstations showed that as noise becomes more complex and contains more information, task processing times get longer and/or the rate of errors increases. The noise interference levels were between 40 dB(A) and 70 dB(A) which corresponds at least to the level observed in schools (see section 1.3).
In their investigations KLATTE ET AL. (2003) were able to provide concrete evidence of the effects of noise interference in the memory performances of primary pupils. Laboratory tests verified that other acoustic information interfered with the retention of information conveyed in writing via the phonological working memory. Interference by foreign language words of one syllable revealed no difference in the memory performance. However, in the case of six-syllable words the error rate was found to increase considerably. Staccato music had the same effect. The authors discovered no influence of the intelligibility of the noise-interference on the degree of interference. Nor did they find that those people investigated became used to the noise interference. As an explanation one may accept a direct connection between auditory perception and the phonological working memory. These demonstrable interferences for individual cognitive processes add up to a considerable interference of the reception and processing of information and thus on "scholastic performance" overall. BORMANN ET AL. obtained similar findings (2003) for children with diminished hearing. HUBER AND ODERSKY (2000)'s compilation shows the many aspects of the effects of interference on the hearing process with regard to listening, understanding and learning. However they also show ways of countering these problems, at least in a pedagogical framework. In their investigations GREEN, PASTERNACK AND SHORE demonstrated a clear relationship between noise load (average level between 60 and 68 dB(A) with peak values caused by airplanes of up to 96 dB(A) and reading capability.
In a laboratory study MASSARO (1977) has shown how auditory information processes sing is interrupted by an audio signal emitted at varying intervals (with no information content) depending upon the time delay. At an interval of up to 100 msec. the error rate was 30 %, after which the interference effect lessened. This masking function plays a major role, particularly at very short distances between the useful and interference signals such as occur, for instance, in the case of reflections within a room.
FRANCOIS AND VALLET summarise the interference caused by noise in schools again in a WHO statement on the subject of "Noise in Schools": The intelligibility of verbal communication is reduced by loud environmental noise, difficulties in learning from written and spoken sources, delayed speech development, diminished reading capability and reduction of the active vocabulary are the most important elements. According to WHO, particular attention should be paid to the room acoustics of buildings to reflect the changed use of school buildings. They also recommend an noise-interference limit of 30 dB(A).

2.1.2 Acoustic parameters in educational establishments

It is evident that schools are loud buildings (see section 1.3). Also, predominantly people cause the sounds in schools and not machinery as elsewhere. Noise is determined by the process of teaching itself and is caused by the individual working procedures and the behaviour of every individual as well as the overall class community. Noise in schools is produced in the classrooms, not by them (see section 2.1.1). On the other hand, the actual noise level in the classroom, as elsewhere, is determined not only by the original emissions but also by the room's acoustic properties. These affect the time taken for the sound to decay and for the sound to be distributed. As a "medium“ between the speaker and the hearer the room has a further particular significance for the clarity and intelligibility of the speech signal as it is received by the hearer. In a discussion of "noise in schools“ therefore it is essential to include the room acoustics in the list of parameters involved in such a situation.
If we consider the suitability of classrooms for their purpose, i.e. from a room acoustic perspective, the acoustic scientist may use the term "hearability" for a whole series of characteristic values. Table 2.2 lists the room acoustical criteria for various hearing impressions as found in corresponding standard works (see. e. g. FASOLD AND VERES).

Table 2.2 Room acoustical criteria for different hearing impressions according to FASOLD AND VERES

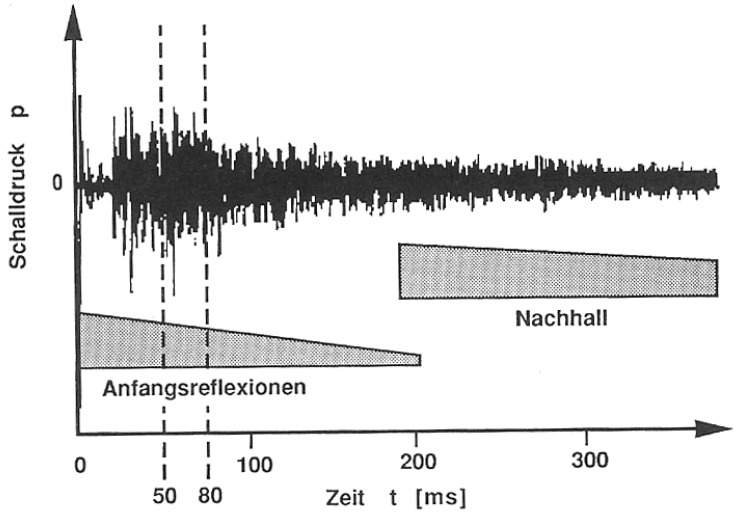
Hearing impression	***Criteria***
Reverberation, timbre	Reverberation time *RT*
	Early decay time *EDT*
	Bass ratio *BR*
Clarity	Degree of clarity $Direct_{50}$
Transparency, speech intelligibility	Clarity measurement C_{50}
	Articulation loss of consonants Al_{cons}
	Speech transfer index *STI* and/or *RASTI*
Room impression	Hall measurement *H*
	Lateral noise level *LF*
Volume	Sound intensity level reduction Δl

The *liveness* of the room is evaluated along with the criterion of its Reverberation Time *RT*, which is generally judged to be the most influential acoustic property. It is also essential to answer the question of how fast the purely physical properties of a classroom enable sound to decay. In this case a short "reverberation time“ plays a twofold role in practice. On the one hand it contributes to reducing the noise level by rapidly absorbing the sound energy in the room while on the other hand it increases the so-called "speech intelligibility“ and/or "hearability" in the room because the speech signal is clearer. The previous chapter covered the significance of speech intelligibility for the reception of information on the part of hearers, particularly

children, in detail. The basic relationship is physically extremely simple and has been verified for decades in the corresponding literature (see below).

2.1.2.1 Reverberation time and Sabine's Formula

The reverberation time RT according to Fig. 2.2 expresses the time taken after the end of a sound emission in a room for the sound intensity to fall to one thousandth of its initial value, which corresponds to a volume reduction of 60 dB (Fig. 2.3). The criterion was defined by Wallace C. SABINE (1868-1919) at the turn of the previous century and as such represents the earliest and most well known room acoustic quality. Figure 2.2 shows the distribution of sound energy within a hearing environment on the basis of a typical "room impulse response".



Schalldruck p — Sound intensity p
Anfangsreflexionen — Early reflections
Nachhall — Reverberation
Zeit t — Time t

Fig. 2.2 Example of a room impulse response. Illustration taken from FASOLD AND VERES, P.135.

It marks the difference between "reverberation" (> 200 ms) and early reflections, beyond which according to general opinion the ear cannot distinguish the sound energy components from the primary sound up to approx. 50 ms in a speech context. According to the *Sabine's Formula* (below) the reverberation time is directly dependent on the room's dimensional volume and its absorption equipment:

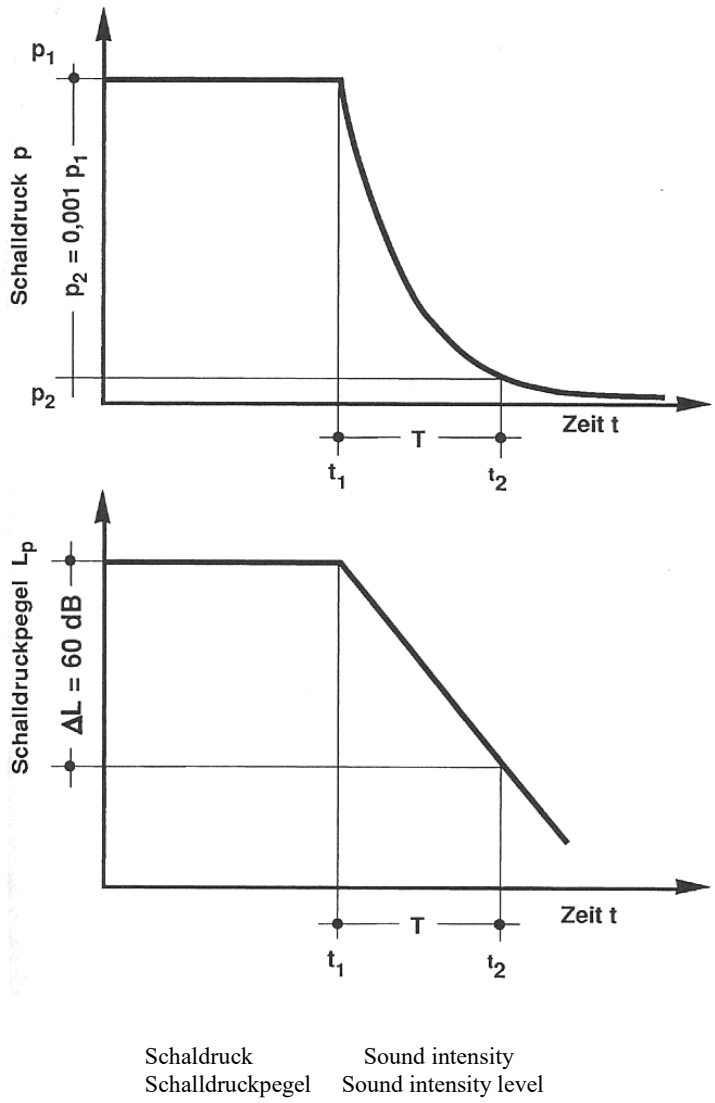
$$RT = 55.3\ V/A * c_0 = 0.163\ V/A\ [s]$$

in which: V is room volume in m³
c_0 is the speed of sound dispersion in air; $c_0 \approx 340$ m/s
A is the equivalent sound absorption area in m².

I.e. it increases as dimensional volumes in similarly equipped rooms increase and falls in rooms of a similar size as the absorbing equipment is increased.

On closer examination of the Sabine's Formula it becomes clear, however, that even with complete sound absorption (A = 1) the reverberation time does not fall to zero. A residual reverberation time remains (see MASUHR). In fact the Sabine reverberation equation represents only an approximation in the case of rooms with no significant sound absorption properties. It is sufficiently accurate for average absorption rates up to α_{room} = 0.3. It is therefore applicable for the range of parameters that occur with respect to the overall absorption surface in normally furnished, acoustically equipped and occupied classrooms. If in doubt it is worth checking on the basis of EYRING'S reverberation time formula:

$$RT = 0.163\ V/-ln(1-\alpha_{room})\ S_{ges}\ [s]$$



Schaldruck — Sound intensity
Schalldruckpegel — Sound intensity level

Fig. 2.3 Schematic illustration of the reverberation process for sound intensity *p* and for the sound intensity level L_p; Illustration taken from FASOLD AND VERES, P. 137.

Another problem with respect to the applicability of the Sabine's Formula is the frequent lack of diffusion in classrooms due to its volume dimensions and sparse furnishings. A possible mathematical procedure by NILSSON for estimating these non-

diffuse noise fields is given in Appendix D of DIN EN 12354-6. At the end of the '90s BRADLEY AND BISTAFA once more offered for consideration the fact that the 100% diffuse noise field required for the application of the Sabine's Formula almost never occurs in classrooms, for which reason preliminary calculations of reverberation times on this basis are consistently too low as compared to a measured value. In their comparison of different processes used for classroom calculations, the application of the Sabine's Formula was found to be subject to an average mathematical error of 21.5%. Individual deviations of above 40 % were determined for rooms in which only one surface with was fitted with absorption material.
Nor does the original Sabine's Formula take into consideration the air dissipation (influence of air damping on the level reduction). This is negligible however in the present classrooms due to the low room noise level even at higher frequencies and is not taken into further consideration in the following.
Since a level dynamic of 60 dB cannot usually be achieved in field measurements, the reverberation time is determined in practice by a drop in the noise level of -5 dB to -35 dB (so-called T_{30}) and/or of -5 dB to -25 dB (so-called T_{20}). In addition, subjective surveys (generally related to musical performances) provided unsatisfactory correlations between the measured reverberation time and the perceived reverberation duration (see FASOLD AND VERES). As a result, the early portion of the decay process, which agrees more closely with the subjectively perceived reverberation process as compared to the reverberation time, is frequently measured as well as the reverberation time RT. A 10 dB drop in noise level is generally determined for this "Early Decay Time" EDT (in some cases as much as 15 or 20 dB).
In virtually cubic rooms in which none of the room dimensions is more than three times greater than the others, the sound intensity level reduction caused by the absorbent surfaces in the room can be mathematically described (see. e.g. FASOLD AND VERES). The direct noise level $l_{p\ dir}$ prevails in the vicinity of the sound source. As one moves further away from the sound source (in the case of teaching this is usually the person who is speaking at the time) the noise level reduction is similar to that found outdoors (outdoor sound field). At a certain distance from the speaker however there is a constant sound intensity level, the so-called "diffuse sound field": $l_{p\ direct}$. This diffuse sound intensity level is lower, the greater the room's equivalent sound absorption surface, according to the following equation:

$$L_{p\ direct} = L_W - 10\ lg\ A/4\ [dB]$$

in which

$l_{p\ diff}$	is the diffuse sound intensity level
l_W	is the sound output level from the sound source and
A	is the equivalent absorption surface of the room.

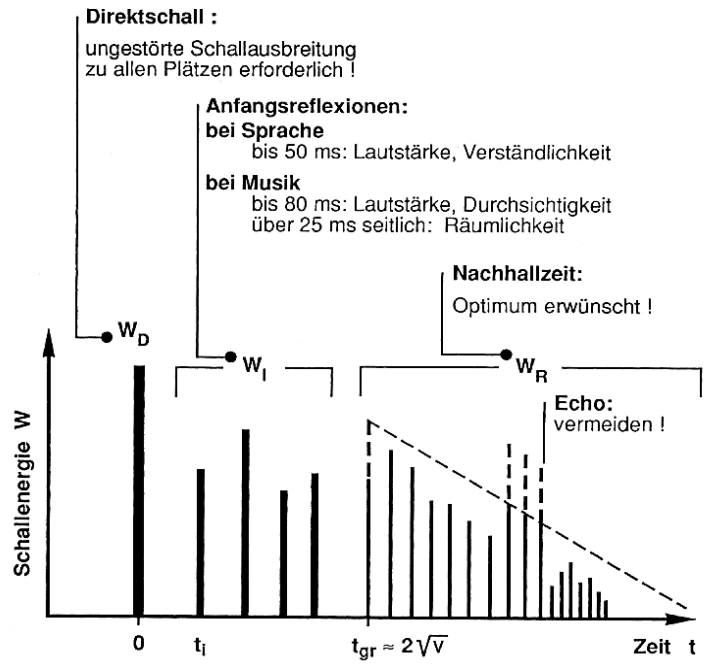
The expected noise level reduction of the diffuse sound field due to the increase of the absorption surface can be therefore determined as follows:

$$\Delta l = 10\ lg\ (A_1 + \Delta A)/A_1$$

If one doubles the start value A1 of the untreated room one obtains a noise level reduction Δl of 3 dB.

2.1.2.2 <u>Speech intelligibility</u>

The acoustic values that influence the hearability in classrooms are basically the volume of the acoustic perception of useful and interference signals, the sound field structure (sound reflection process) including the frequency-specific value of the reverberation time and the reconciliation of the optical and acoustic direction orientation (see TENNHARDT, 2003). Since the previous chapter covered the influential factor of "noise interference" in great detail, the next section concentrates only on the influential factors of reverberation time and sound field structure.



W_D Direct noise: uninterrupted noise dispersion to all places required
W_I Early reflections: during speech, up to 50 ms: volume, intelligibility,
during music: up to 80 ms: volume, transparency,
over 25 ms lateral: spatiousness
W_R Reverberation time: optimum required
Echo: vermeiden = Echo: avoid
Schallenergie = Sound energy
Zeit = Time

Fig. 2.4 Schematic room impulse response. Illustration taken from FASOLD AND VERES, P.149.
t_i: Time between direct sound and early reflection in ms
t_{gr}: Time limit for the transfer of early reflections to diffuse reflections (reverberation) in ms
V: Volume in m³

If one extrapolates a schematic trend of the sound energies from the room impulse response illustrated in Figure 2.2, one can see the significance of each of the individual values with respect to speech intelligibility at the hearer's location (Fig. 2.4). An essential quality feature here is the ratio of the energies of direct sound W_D, early reflections W_i and reverberation W_R.

Normally the early reflections occurring within 50 ms have an amplifying effect and are thereby classified as clarity increasing while energy-rich sound reflections after 50 ms and echo and/or flutter echo effects are considered to be detrimental to speech-intelligibility. However representatives of hearing impaired organisations, for example, refer to the fact that this limit value applies only for those with full hearing capabilities. The relevant literature correspondingly contains numerical values of 30 ms as the transition time between useful and interfering reverberations (see e. g. RUHE, 2000). The practical effect of this energy distribution lies ultimately in the "speech intelligibility“ of a particular room. This is expressed objectively and comparatively simply by the criterion *Degree of clarity* D_{50}

$$D_{50} = W_{0\text{-}50ms}/W_{ges}$$

and/or *Clarity measurement* C_{50}

$$C_{50} = 10 \lg W_{0\text{-}50ms}/W_{50ms\text{-}\infty} = 10 \lg D_{50}/1\text{-}D_{50} \text{ [dB]}$$

.
If the actual intelligibility in a room is to be determined with greater statistical certainty, test hearers are asked also to record spoken sentences, words or syllables. The most common is the transcription of logatomes, non-meaning carrying syllables, comprising three phonemes: a consonant, a vowel and another consonant. In this case, a syllable intelligibility of more than 50 % is described as "good“ while more than 70 % is "very good“. (For details see. e. g. FASOLD, SONNTAG, WINKLER)
One objective process used today for describing speech intelligibility is the so-called *"Speech Transmission Index“ (STI)* and/or its abbreviated version "Rapid Speech Transmission Index“ (RASTI) according to HOUTGAST AND STEENECKEN. It is based on the fact that speech can be detected as an amplitude-modulated signal. An evaluation is accordingly made of how noise interference, reflections and reverberation reduce the depth of modulation of an amplitude-modulated signal in a room. The evaluation takes place over the 7 octaves from 125 Hz to 8 kHz and 14 modulation frequencies F from 0.63 Hz to 12.5 Hz. The STI is calculated from the resulting modulation transfer functions according to a fixed scheme. The following applies with respect to the evaluation of speech intelligibility (see Table. 2.3):

Finally it is worth mentioning one more process which was originally developed to optimise public address systems: the articulation loss of consonants *(Articulation Loss of Consonants)* Al_{cons} (seePEUTZ and KLEIN):

$$Al_{cons} \approx 0.65\ (s/r_H)^2 * T \text{ [\%]}$$

with s distance between the sound source and the hearer in m
r_H Hall radius in m
T Reverberation time in s

Table 2.3 Evaluation of the Speech Transmission Index STI

STI	Evaluation
0 to 0.30	unsatisfactory

0.45 to 0.60	satisfactory
0.60 to 0.75	good
0.75 to 1.00	very good

In this case the AI_{cons} for a "workable“ intelligibility must be less than 15 %, less than 10 % for "good“ intelligibility and less than 5 % for "excellent“ intelligibility. The values obtained from the equation however require a minimum signal-to-noise ratio of around 30 dB and deteriorate considerably if this falls. According to FASOLD AND VERES the STI can be expected to double at a SNR of just 20 dB.
The process is of interest because from a linguistic perspective the consonants are of particular significance for the intelligibility of the content. Particularly plosives and fricatives (p, t, k, f, ss, z, sh) function partly due to their numerical frequency and above average frequency as meaning-carrying elements of a syllable and/or a morphemes (smallest element of speech that can transfer meaning) (vgl. BERGMANN, PAULY, SCHLAEFER). The spectrum of the above fricative and plosive sounds contains predominantly high-frequency acoustic signals (1 kHz – 8 kHz). The base tones and vowels which create the volume of the voice, however, are predominantly low-frequency (125 Hz – 250 Hz and/or 250 Hz – 1 kHz). While the latter are particularly responsible for the sound of the voice, the consonants determine their articulation. The differing importance of various speech elements for speech intelligibility can be effectively demonstrated by whispering. Although the speech signal lacks the vibration of the vocal chords during whispering, i.e. it comprises exclusively aspiratives, sibilants and plosives, the content is easily understood provided the signal is sufficiently loud with respect to the noise interference. However a lot of noise interference – like speech – contains intensive high-frequency spectral percentages. An interesting onomatopoeic compilation of interference noises can be found in RUHE (2003A).

One logical consequence is a correspondingly intensive damping of the high-frequency noise interference. However, RUHE considers intensive damping of low frequencies as less urgent. In his study, none of the questioned persons expressed negative opinions about low-frequency reverberation if the reverberation time was within the "sufficiently short“ average frequency range of between 250 Hz and 2 kHz. A teaching room, for instance, in which the reverberation time at 100 Hz was almost double that within the average frequency range, was evaluated as good by the users (RUHE, 2003b). The reason is the rather weak excitation of these frequencies themselves by the bass tones of male speech (see MASUHR). This negligibility of low frequencies is disputed amongst experts. Advocates of equipping communications rooms to absorb more low frequency refer for example to the masking effect of low frequency interference noise. In this context MOMMERTZ (2002) reminds us a target group particularly subject to this effect: "Mehr als 30 % aller Kinder and Jugendlichen haben einen zeitweiligen oder bereits beginnenden dauernden Hörschaden“. (More than 30% of all children and young people have temporary hearing damage or are in the early stages of permanent hearing damage.) However, the significance of frequencies will not be discussed further in this investigation.

2.1.2.3 The mutual dependency of reverberation time and speech intelligibility

The two characteristic values of reverberation time and speech intelligibility are mutually dependant to a great extent. If the reverberation time is too long, this affects the speech signal in that subsequent syllables are overlaid by the extended decay of the previous ones. The reverberation time also falls as the reverberation increases while the noise level remains the same. The literature frequently shows the following table which provides an overview of syllable intelligibility according to FINITZO-HEIBER AND TILLMAN (1978), see for instance MCKENZIE AND AIREY or TENNHARDT (table 2.4). TENNHARDT rates a syllable intelligibility of 0 to 34 % as "poor“, of 34 to 48 % as "inadequate“, of 48 to 67 % as "good“, from 67 to 90 % as "very good“ and more as "excellent“. All numerical values in the table that indicate poor or inadequate syllable intelligibility are therefore given in italics: Accordingly, extremely quiet rooms with an average reverberation time of 1.2 sec are unsuitable for those with hearing difficulties. And even with a very short decay of only 0.4 sec, hearing impaired persons require a SNR of at least 12 dB(A) for a "good“ speech signal. This condition is certainly transferable to children who already require a good SNR (see again section 2.1.1). TENNHARDT (2003) furthermore proposes that the evaluation criteria should be shifted one stage back for non-mother tongue communication (e.g. foreign language teaching or teaching children in a language other than their mother tongue) so that a "good“ rating requires a syllable intelligibility of 67 %.

Table 2.4 Syllable intelligibility in relation to the reverberation time and the signal-to-noise ratio according to FINITZO-HEIBER AND TILLMAN

	RT = 0 sec		**RT = 0.4 sec**		**RT = 1.2 sec**	
SNR in dB(A)	**Normal hearing-**	**Hearing impaired**	**Normal hearing**	**Hearing impaired**	**Normal hearing**	**Hearing impaired**
> 45	94.5	83.0	92.5	74.0	76.5	*45.0*
12	89.2	70.0	82.8	60.2	68.8	*41.2*
6	79.7	59.5	71.3	*47.7*	54.2	*27.0*
0	60.2	*39.0*	*47.7*	*27.8*	*29.7*	*11.2*

The relationship of reverberation time and speech intelligibility can also be shown on the basis of physical characteristics. MOMMERTZ (2001), for instance, reports of a high correlation both between STI and degree of clarity as well as between STI and T15 and between STI and EDT in room acoustic simulations of classrooms with average reverberation times of between 0.3 and 0.8 sec and comparable noise interference levels.

2.1.2.4 The search for the optimum reverberation time for classrooms

On this basis therefore one is bound to ask which room acoustic conditions provide an adequate framework for the changed pedagogical requirements described in section 1.2. To put it more simply, how can we create the "classroom as a tool“ that offers pupils and teachers the optimum working conditions for modern teaching?
Until the 80s, both technical standards and specialist literature specified an average reverberation time of 0.7 or 0.8 sec as a guideline value for rooms used for speech measuring approx. 200 m³ (which corresponds to a normal classroom according to empirical findings).
Research into the effects of a reduced reverberation time and thus an improved speech intelligibility on the teaching events is not as new as one might assume given the current debate. Just a short time ago, a relatively unknown 30-year old investigation by EßMANN (1970) on classroom acoustics in the former DDR was rediscovered. Using syllable indelibility measurements, recounted foreign language texts and arithmetical testing it was demonstrated that pupil performances depend to a significant extent on the room acoustics. However, an extremely live classroom (average reverberation time RT approx. 1.2 sec when occupied) was used for the test which was compared with the state of the technology at that time (average reverberation time RT approx. 0.9 sec when occupied).

Since the 80s the question of the optimum reverberation time for the teaching situation has been re-addressed with a demand for considerably lower values. At the start of the 90s Pekkarinnen and Viljanen (1990) determined in a random survey of 31 classrooms that only twelve of these 31 rooms fulfilled the then specifications of the Finnish authorities of reverberation times between 0.6 and 0.9 sec (250 HZ – 2 KHZ). Furthermore only two of the twelve classrooms achieved a RASTI-value of 0.75 ("Very good“) in speech intelligibility measurements. In further investigations of typical classrooms it emerged that only classrooms with an average reverberation time of less than 0.6 sec guaranteed universally excellent speech intelligibility (STI > 0.75). In a detailed follow-up investigation (PEKKARINNEN AND VILJANEN, 1991) the reverberation time of far more than 1 sec was reduced to less than 0.7 sec (500 Hz - 2 kHz) in a test classroom measuring 9.5 x 6.5 x 3.5 m with glass wool absorbers on parts of the ceiling and the back wall. As expected, the reduction of the reverberation time also improved the speech intelligibility (see. 2.1.2.3). However, it became clear at the same time that the higher the noise level the greater was the influence of the absorbing measures on the speech intelligibility. According to BRADLEY (1986), therefore, they assume the optimum average reverberation time of between 0.4 and 0.5 sec for speech communication. The results from Finland were ultimately confirmed in 1999 by MCKENZIE AND AIREY in the most extensive field study into classroom acoustics to date. The two scientists from the Heriot-Watt-University, Edinburgh also reduced the average reverberation time from 0.8 sec to under 0.5 sec in various test classrooms and refer particularly in this context to the changed pupil behaviour and the considerably reduced consonant loss (Al_{cons}) thanks to the refurbishment in the classroom. The ACOUSTICAL SOCIETY OF AMERICA published recommendations for the acoustic design of rooms depending their use, e.g. a RT from 0.4 to 0.6 sec for empty classrooms or music rooms from 0.6 to 1.1 sec. In classrooms used for teaching, particular reference is made to the fact that this applies for both direct teaching and for pupil centred work in small groups.
Thus the question remained as to whether such heavily attenuated rooms have negative effects on subjective feelings of well-being. However, at the Lund Institute of

Technology NILSSON AND HAMMER (1995) verified – contrary to certain earlier received opinions – that even reverberation times of around 0.4 sec were evaluated as very beneficial by many test subjects. RUHE (2003b) also refers to the fact that in heavily attenuated normal-sized classrooms the signal-to-noise ratio is not even threatened at the back of the room. The concurrently greatly reduced noise interference level, particularly due to the changed pupil behaviour compensates for the reduced useful signal level resulting from the additional absorption surface. However, the spatial limits of heavily attenuated classrooms are also revealed. A room, particularly with an all-over attenuating ceiling lining, should not exceed a length of 9 m. DIN 18041 specifies a maximum room size of 250 m³ for the installation of all-over heavy room attenuation.
The debate about shorter reverberation times for classrooms was temporarily halted by the latest re-issue of DIN 18041 (2004). Its specifications for standard classrooms with required reverberation times of around 0.5 sec accord with the international research status. The standard especially addresses important pedagogical problems such as foreign language teaching, teaching pupils in languages other than their mother tongue or pupils with attentiveness- and concentration disorders.
A look at the actual building substance – at least based on the few available statistics – shows a very differentiated picture. Investigations reveal an astounding breadth of variation on acoustic quality. For instance, MASUHR reports on a random investigation of 31 teaching rooms in the Kreis Herzogtum Lauenburg. Of those classrooms appraised, 17 failed to meet the requirements of the new DIN 18041, and 14 rooms (44 %) revealed some serious deviations. RUHE (2003b) reports from his consultancy experience on numerous classrooms with average reverberation times of far more than 1 sec. His portrayal is certainly unrepresentative since as a consultant engineer, he is primarily contacted when problems arise. However he reports a striking rate of complaints by teachers at an average reverberation time of above around 1.25 sec.

The fact that teachers and pupils are largely indifferent with respect to the room acoustic properties of their classroom in subjective surveys and do not complain until conditions are really unsatisfactory was also confirmed in the Heriot-Watt study (MCKENZIE AND AIREY, 1999). Is this a phenomenon due to a lack of sensitivity and perception or are the effects of room acoustics on teaching events actually not so clearly discernible in practice? One needs to ask the question:

What relationship exists between the noise load in teaching and the associated ergonomic parameter of room acoustics? And what is the significance of this relationship with regard to the changed courses of communication in the classroom outlined in section 1.2?

The particular strengths of interdisciplinary methods are now reasserted. To answer this question requires a process in which the relevant framework conditions of room acoustics, noise level and pedagogical operational method are objectively related to one another. The development of this process is henceforth the central task of this investigation.

2.2 Teacher-stress

2.2.1 Stress responses

Everyday experience is sufficient to tell us that the heart beats faster when one is involved in physical activities, e.g. running or climbing stairs than when one is lying down and relaxing. The state of physical excitation produces a similar reaction, e.g. when one is angry or happy, i.e. when one is experiencing strong emotions. The cardiovascular system thus responds continuously to any demand that is placed on the organism, even by cognitive processes that do not entail strong emotional stimulation. This continuous adjustment of the corporeal functions to external demands serves to maintain the homeostasis (SELYE, 1981). This process is generally described as the stress process with none of the negative connotations colloquially ascribed to the term stress. On the contrary, it is the process of adaptation which predicates survival, at least in this general form.

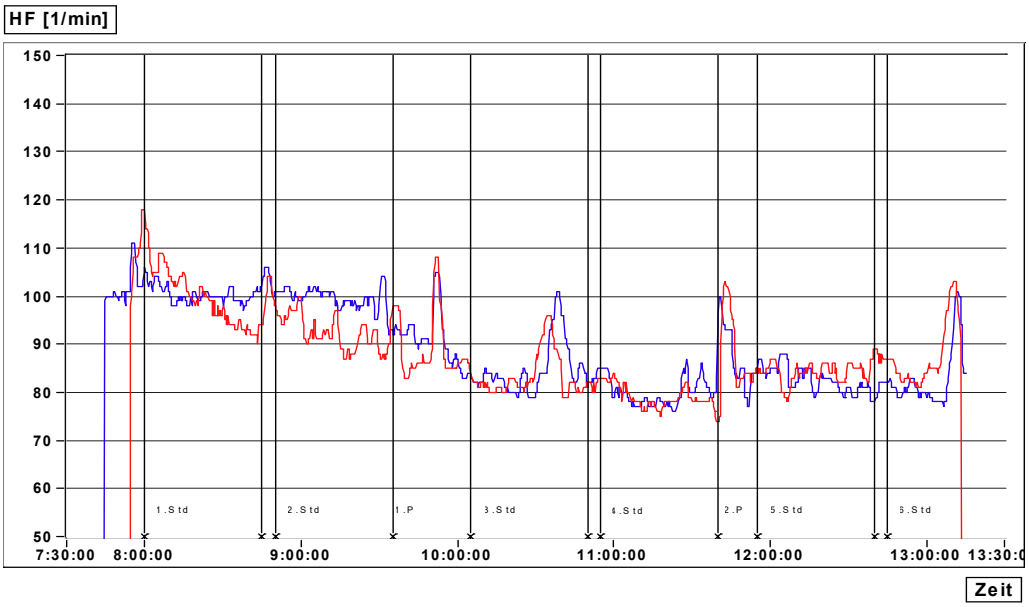
A continuous record of the heart rate shows this constant process of adaptation in all its manifestations. Thus one finds constant switching from acceleration to deceleration, of physical excitement and relaxation in different phases of cognitive activity. One might view this kind of record to a certain extent as a record of changing psychophysical situations that the affected person has endured.

If one takes the occupational science "load-stress model" illustrated in section 1.1 as a starting point, this kind of heart rate monitor record reflects the course of stress reactions of the affected person. In this case note that the measured *stress* is the result of all *loads* to which the person was exposed at that time. In the context of a workplace analysis these loads basically comprise the task, the working environment and the working conditions along with the personal characteristics of the persons involved. When one speaks about psychophysical stress one is referring to the fact that some stress reactions are manifested as corporeal (physical) events, but are in many cases triggered or modified by mental (psychological) processes. If one wants to describe stress caused by work it is necessary to analyse these stress responses within the work process. Occupational science has opted for reading pulse or heart rates with mobile ECG recorders as a preferred means of indicating stress. The benefit of this technique is the practically unlimited mobility of the test subjects and the virtual imperceptibility of the device when in use.

As shown earlier, the heart rate signal emitted by the cardiovascular system is extremely sensitive to stimulus, i.e., the slightest disturbance of the homeostasis causes this parameter to change, the disadvantage being the extremely non-specific nature of the reaction, i.e. it is impossible to determine the nature of the stimulus e.g. anger or joy, from the response. It is, however, easy to compensate for this disadvantage of the parameter, ideally by means of as accurate an activity record as possible. This should include both physical and psychological events, stair climbing or resting, or even the type of activity or emotional states if possible. The interpretation of this kind of record depends substantially on the accuracy of the heart rate monitor record.

Apart from medical-clinical aspects of the heart rate, stress analysis essentially uses two framework conditions (see SCHANDRY), which are defined on the basis of their temporal relation to external events: The *tonic* percentage of the heart rate incorporates the basic activation which is determined by long sustained effects of events, activities, states etc. In contrast, the *phasic* percentages, i.e. fast reactions to momentary events, e.g. sudden racing heart in a fear situation. The separation of the two framework conditions is only possible to a limited degree. The significance of this fact for the present investigation will be addressed in more detail in section 4.3. Both tonic as well as phasic portions are relevant in the analysis of working stress.

These kinds of analyses were carried out for teachers in an investigation into load and stress in the teaching profession by Schönwälder et al. (2003). Amongst other things it posed the question of the reproducibility, and therefore also the reliability of the stress trends. To this end daily profiles of the heart rates of 16 teachers were recorded on the same weekday of two consecutive teaching weeks (week day with the highest number of lessons). The resulting profiles were practically identical for all 14 persons. Figure 2.5 shows one example. A clear difference was determined for only two teachers. The course of the heart rate in the second week was identical but was 15 to 20 beats per minute higher than in the first week. While for the remainder both the phasic and the tonic portions were almost identical, the two differ only in their tonic percentage. The phasic portions were also identical. When the two parties were questioned in retrospect, this difference was explained by a very strong physical excitement triggered by psychosocial conflict situations. The influence of personal constitutional characteristics on such a globally reacting parameter is clearly shown, as is the accuracy with which the phasic portions mirror the working stress.



Zeit = Time
HF = Heart rate

Fig. 2.5 Daily heart rate profile of a person on two identical weekdays in consecutive weeks following practically identical procedures. According to SCHÖNWÄLDER ET AL. (2003)

Another example of measuring stress based on the heart rate is found in BERNDT ET AL. (1988) with an investigation of the school working environment. This example, however, focuses on pupil stress in teaching situations. With their investigation the authors show firstly the significant load caused by the teaching situation, which is identical for all children including in terms of the measured reaction, and secondly the function of the psychosocial characteristics of the pupils for the ways in which they react (see Fig. 2.6).

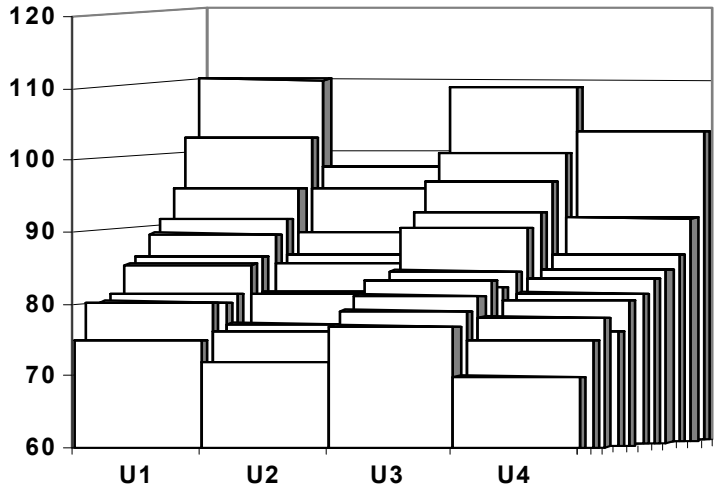


Fig. 2.6 Daily heart rate profiles (average values during lessons) of 16 children in a year 4 class. From BERNDT ET AL. (1988)

The illustration clearly shows the relationship between stress and lessons: It affects all children in the same way. The ranking correlation produced values of between r = 0.90 and r = 0.97. This confirms the great significance of the phasic part in the reaction, but also shows the very significant tonic percentage, which was essentially determined by phsycho-social functions, e.g. pressure from parents to perform.
The heart rate monitor record has been proven to be a suitable stress indicator in occupational science. In conjunction with a precise observation record it is possible to draw more detailed conclusions, as has been hitherto standard practice in this field (see section 4.1).

2.2.2 Physiological working curve

If one observes the work rate of an individual over a predetermined period, one discovers that it is not constant. It can therefore be assumed that the work rate at the start of the working day is higher than at the end. This process is described as fatigue brought about by a person's output (ROHMERT AND RUTENFRANZ, 1983). The degree of fatigue observed is particularly determined by the activity itself but is also influenced by other values, which are partly determined by the work system and partly by the person him/herself. The demands imposed by the work system can generally be described in terms of purely physical parameters: climate, output, time structure, etc. Influencing factors determined by the individual include e.g. their skills and abilities, motivation etc. In an unrelated context it was also observed that a generally applicable physiological work curve underlies the work rate (see Fig. 2.7). The performance distribution shows a clear dependency on the time of day.

This circadian period also determines amongst other things the individual sleep/wake ratio. It is largely autonomously controlled by the central nervous system, which is substantially influenced by daylight. This daily work rate distribution was determined on the basis of error rates in office activities (BERNER cited according to ROHMERT AND RUTENFRANZ, 1983. However, it has also been found in later investigations (e.g.

GRAF, according to ROHMERT AND RUTENFRANZ) for other activities. This physiological work curve applies more or less obviously with some slight shifts for all individuals in the same location.
This kind of circadian period is also found in the case of physiological parameters, if not always following the same course. For instance, the progression during sleep is predominantly multiphase while the progression trend itself is very similar. This basic circadian rhythm generally underlies all other influences, thereby determining a natural course of activation and fatigue. Occupational science practitioners make use of this knowledge insofar as working structures in many places are adapted to these biological predispositions (ROHMERT AND RUTENFRANZ, 1983). A study by HELLBRÜGGE ET AL. (1960) refers to precisely this phenomenon of a daily cycle, proposing that this be taken into consideration when planning timetables for specific subjects. It is not known how much this recommendation has been taken into consideration in the last 45 years.

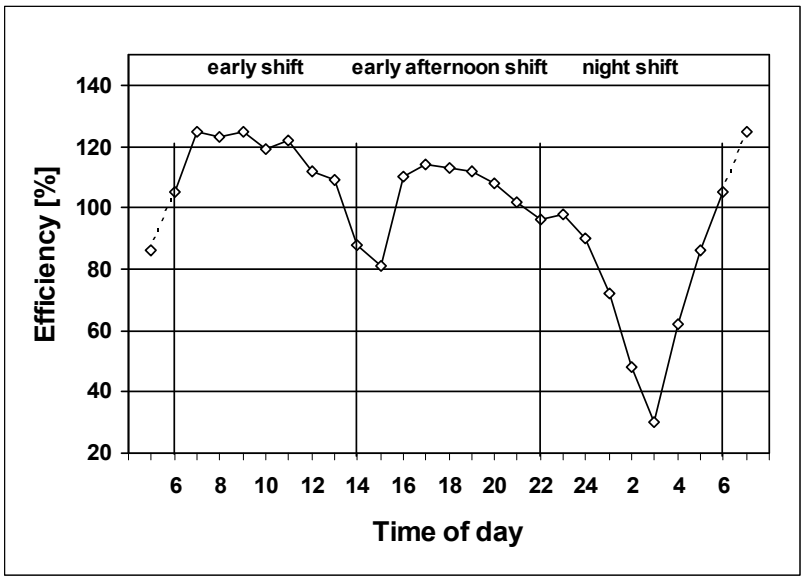


Fig. 2.7 Daily course of work distribution, according to ROHMERT AND RUTENFRANZ, 1983

Longer periods are evident along with this circadian period. There is for instance an annual cycle that is determined by the climate at least in central Europe. Other rhythms are determined by social conditions, for instance, the weekly rhythm and the holiday rhythm. These rhythms are not discussed further here since they would require a considerably broader investigative approach. The significance of the weekly rhythm is addressed in more detail in the work of SCHÖNWÄLDER ET AL. (2003). The authors found an increase of activation mid-week and a stark reduction of fatigue at the weekend.
This circadian rhythm of the level of activation or work distribution is overlaid by further influences, which could mean fatigue as well as additional activation. A vivid example of additional activation is the sportsperson warming up for an impending competition which means that all the organic systems required for motor activity are instructed to prepare for increased output. An impending cognitive test situation has similar effects and can also be seen in terms of activation. Both cases involve stress processes. The opposite, fatigue, always occurs after performance has been carried out. The degree of fatigue depends on the level and duration of the preceding work,

but also on state of the individual at the start of the activity. A typical example is the performance of work after an undisturbed phase of sleep and/or after a disturbed or even absence of sleep phase. An overview of the relationship between fatigue and restoration is given by QUAAS (1997) with extensive illustrations from the area of occupational medicine and research into accidents (VALENTIN ET AL., 1979, NORPOTH, 1991), as well as work related to questions of night and shift work (HAHN 1992).
In the context of work rate and fatigue it is also necessary to question how long a break is necessary for restoration to take place. LUCZAK (1983) applies the term 'break' to three levels of physical function:

1. The level of absolute feasibility limits for neuronal and muscular functions, the refractory times necessary to recreate cellular homeostasis. These levels all lie within the millisecond range. These times cannot be influenced. They are resistant to any external manipulation and therefore determine the feasibility limits of the affected organs.
2. A second level is derived from the analysis of work cycles within the second range. These cycles result e.g. in the case of muscular work from the process of contraction and relaxation in which the relaxation phase is once again absolutely essential for the supply of energy to the muscle. Informational work is comprised of a sequence of sensory, discriminatory, combinatory and motor elements, which may take place simultaneously as well as successively. Once again, individual organs require rests in order to ensure their functions over a long period.
3. Not until the third level is the restorative process within the work process cited, e.g. as a meal break. Once again, this is in order to re-balance the deficit caused by work.

Investigations into activation and fatigue in the workplace are generally based on examples, usually individuals or very small groups. The latest investigations with the aid of the heart rate analysis in work situations is illustrated by MYRTEK (2004). In this case changes to the heart rate in relation to small time lapses are positively interpreted as activation and negatively as fatigue. It is possible to a limited extent to draw conclusions from these stress profiles relating to phases of fatigue and/or the effect of breaks in the form of additional activation. SCHÖNWÄLDER ET.AL. undertook to do this both for the teaching day and for the teaching week and observed the above results. The investigation into the restorative impact of breaks during the working day as expressly related to schools was presented as far back as 1896 in a lecture given by FRIEDRICH. He gives very detailed test procedures for measuring the "mental performance ability" using dictation and mathematical tasks and refers to earlier investigations that are still fundamentally relevant. In consequence he proposes an immediate reduction of lessons to far less than 60 min with followed by a break of at least 8 by 10min. which largely corresponds to the normal academic distribution (45 to 15 min). This opinion on corresponding restorative breaks during the school day are reiterated by HELLBRÜGGE (1956) with the instruction to take into account the daily rhythm as well. Both requirements ought to be questioned at least in the light of the trend towards double periods in recent years. The extent to which this lesson duration influences fatigue processes would certainly be another question for interdisciplinary research.
The influence of the ergonomic working environment on the stress of those people working there remains of great significance. At the very least it represents a load value which remains constant day in, day out, apart from deliberately imposed

changes such as the as room acoustic intervention within the context of the research project "Lärm in Bildungsstätten“ (noise in educational institutions) (see SCHÖNWÄLDER ET AL., 2004). At another school involved in the project, two groups of classrooms which differed from the perspective of room acoustics (see chapter 4.1) offered the opportunity to compare working conditions.
Within these framework conditions one must ask the following question:

"What relationship is there between the stress of the teacher and the ergonomic parameter of room acoustics?“

2.3 The interaction of the noise situation and stress

2.3.1 Noise as stress-inducing factor

Based on the stress model according to LAZARUS AND LAUNIER (1981) (see Fig. 2.8), every perceptive process indicates a stimulus situation which is allocated a corresponding significance on the basis of personal evaluation. When one perceives stimuli that differ significantly from a currently perceived pattern, e.g. a flashing light in ones visual range or a particular sound, e.g. a car horn in ones acoustic range, an orientation response is generally the result. This is associated with the directing of ones attention to that signal.
Associated with this reaction is a short-term activation on a physiological level. In a (very simplified) explanation according to SELYE (1981) the hypothalamus and the hypophysis release the two stress hormones adrenalin and cortisol, which in turn increase the overall physical activity on both motor and cognitive levels. If one refers back to the evolutionary process 500,000 years ago, this was certainly necessary for survival. However, in our present time the reaction possibilities have changed somewhat.

The result of an initial evaluation of the stress-inducing factor, in this case "relevant“ or "irrelevant“, then possibly leads to an all clear signal or to a further activation in order to deal with the stress-inducing factor. While the intensity of the stimulus as compared to the actual environment is one key factor for the triggering of the stress process, the other is the result of the evaluation of the stimulus. Hearing ones own name in a conversational environment also leads to an orientation reaction, even if the speaker's volume is no different from the general noise level. The signal content is the significant factor in this case. The result of a second evaluation, should the first have proved "relevant“ determines the subsequent processing. At this point the actual resources are tested with the possible results "will certainly be overcome", "to be seen as a challenge" or "I have insufficient options". Further interaction with the stress-inducing factor and therefore the reaction now depend on this outcome. At this point, coping strategies are brought into play, which may lead to the stress being overcome, as illustrated by KRETSCHMANN or SCHAARSCHMIDT AND FISCHER. This does not however concern the search for causal relationships.
The particular feature of this model of psychological stress is that it describes a continuously ongoing process, as indicated by the revaluation point in Figure 2.8. With respect to the stress-inducing factor "noise“ this might mean that long-term noise, which is perceived as annoying but from which one cannot remove oneself nor immediately counteract, remains a stress-inducing factor with all its physiological effects and sometimes with increasing effect. This stress model is also described as

a transactional *model.* It describes the mutual interaction between the subject and the environment. The individual's behaviour and the reaction can actually change the surrounding situation if only through an emotional response. (The teacher who is annoyed by noise may communicate this to the pupils purely by facial expression and possibly thereby trigger an initial reaction.)

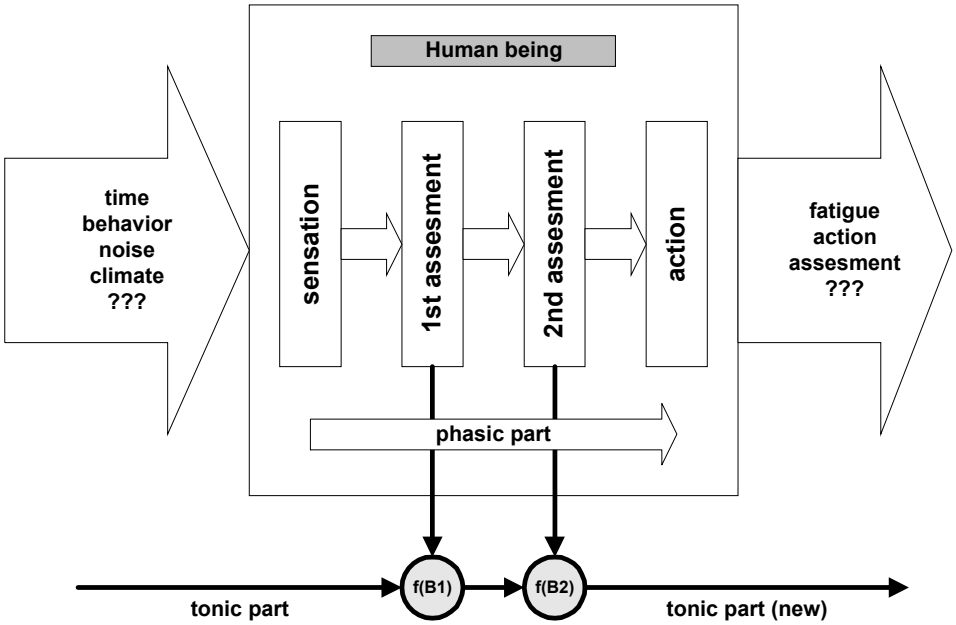


Fig. 2.8 Stress model according to LAZARUS AND LAUNIER (1981)

The physiological reactions to noise, as described in occupational psychology (ROHMERT AND RUTENFRANZ, 1983), encompass the whole spectrum of possible stress reactions with regard to, e.g. the vegetative nerve system, hormone system, cardiovascular system, motor system, perception and digestion. However, no stimulus-specific reaction pattern has been found. Personal reactions vary greatly even in identical noise structures. Noise processing evidently varies greatly between individuals therefore, and is possibly a result of the respective learning and/or socialisation processes related to ones experience or interaction with noise. The reactions that one can observe correspond to the organism's natural process of dealing with this stress-inducing factor. This has been demonstrated in many laboratory experiments. However, the question as to whether there is a possible summative long-term effect is as yet unanswered. The possibility of chronification, while it is constantly referred to in the literature, has not yet been verified.
With respect to noise in schools, FLOSS (1964) reports on of vocational college pupils from various educational areas and their reaction to noise in teaching. He observed changes in the areas of "reflex stimulation, finger tremor, body temperature and heart rate". After 6 hours of teaching at a noise level of 62 to 71 dB(A) the error rate in a fine motor task rose by 18 % (increased finger tremor) but by only 11 % at a noise level of < 40 dB(A). Under the same conditions the body temperature rose in the first case by +0.16 °C, and sank in the second by –0.22 °C. With respect to the stress reaction based on heart rate he observed a relationship with noise level at the place of education. Metalworking pupils experienced no change in stress during loud lessons while technical drawing pupils displayed fatigue to a degree of 4 beats per minute and grammar school pupils by 12 beats per minute. This clearly shows the influence of "normal" working conditions. Another investigation by DÖRING ET AL.

(1971) on infants showed no initial reaction in the range 60-65 dB(A). It measured the change in skin blood flow and revealed a steady reduction of the blood flow (stress reaction) at noise levels above 70 dB(A). However, the threshold reduced in the case of repeated exposure wherein a reaction pointing to an increasing sensitivity to noise was observed. A long term learning process with regard to the interaction with noise was excluded in this case.
The significance of personal coping strategies, particularly with respect to further possible influential factors, is illustrated by SUST AND LAZARUS in Figure 2.9(1997). The phasic percentages of this stress process are presented here as dysregulation, which could become however e.g. chronic dysregulation if influential factors remain unchanged. On the somatic level this is cited as an increased risk for diseases of the cardiovascular and digestive systems.

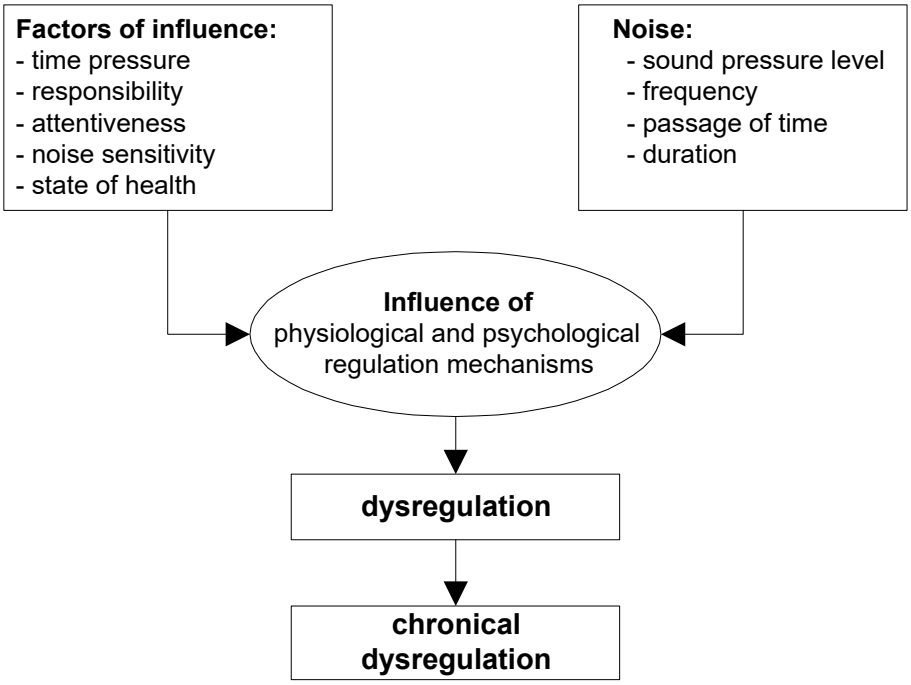


Fig. 2.9 Stress-inducing effects of noise, modified according to SUST AND LAZARUS, 1997

At this point it is worth mentioning once again the workplace model of the school illustrated at the start according to RICHTER AND HACKER who introduced the term, redefinition of the task. In the illustration of SUST AND LAZARUS the redefinition changes the *influence of physiological and psychological regulation mechanisms* and therefore within the scheme belongs to the group of *influential factors.* This central control mechanism is jointly responsible for the course of the subsequent stress processes. This model, like the previously illustrated model according to LAZARUS, is understood as a continuously repeating process, which leads in the short-term to dysregulation as a phasic reaction and to possible chronic dysregulation in the long term. In their investigations into personality structures of teachers, SCHAARSCHMIDT AND FISCHER (2001) found characteristics which are amongst the *influential factors* in the above model but which are also operative in the control mechanism of the *influence*. The significance for the further processing of stress is clear.
In general, research activities relating to the impact of noise on individuals are concerned with the influence of environmental noise g. traffic noise or machine noise. In her investigations STÖLZEL (2004) cites a series of results on the impact of noise

on physiological function but also shows that the reaction is personal. Ideally the effects on the sleep of the person are documented in which case a slight noise level of 45 to 55 dB(A) can cause interference. (Even less in some cases. One only has to think of a fly buzzing around ones head in the summer or a dripping tap). In his investigations BERG (2001) shows that a reduced reverberation time against a background of normal environmental noise considerably improved the sleep quality of the test subjects with no changes to the external noise situation.

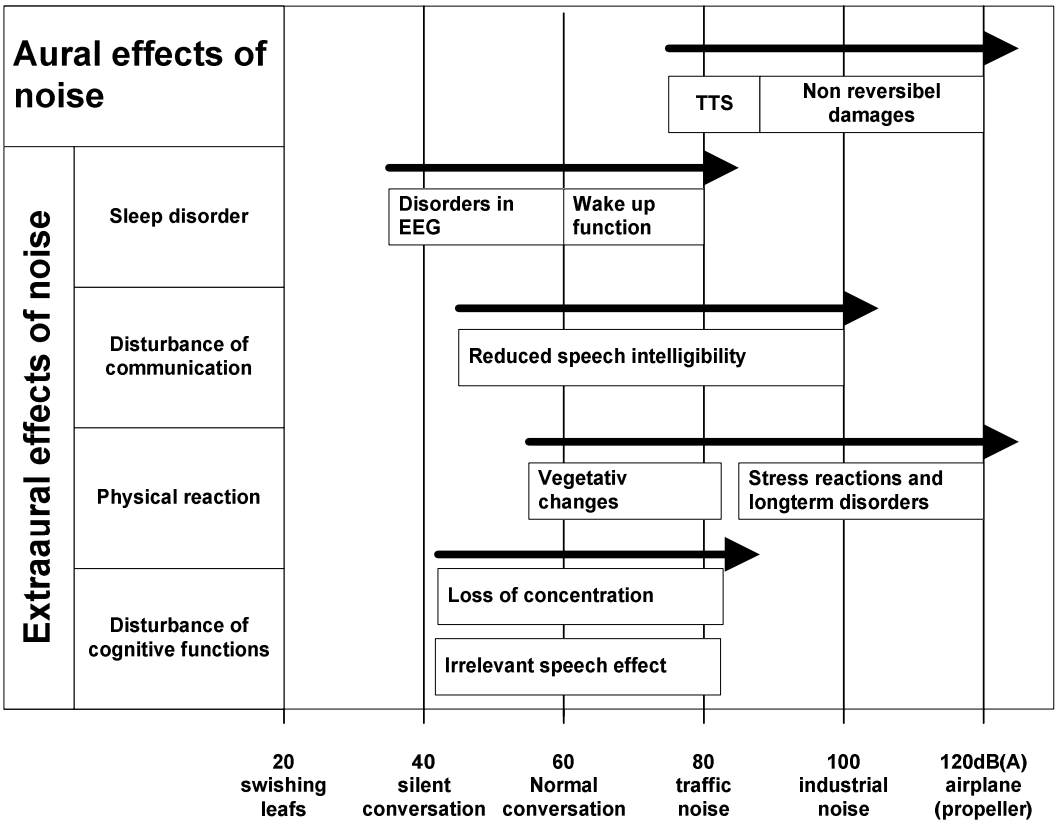


Fig. 2.10 An overview of aural and extraaural noise effects Extract from: Lexikon der Psychologie (lexicon of psychology) (2001)

The aural effects of noise are illustrated in the relevant occupational science literature in the form of "noise-related hearing impairment“. ISING ET AL. (1996) provide an overview-style summary and therefore this subject will not be covered further in this context.

In summary it is possible to determine that noise-related hearing impairment with irreversible hearing loss (TTS) is the only illness for which a causal relationship with noise exposure can be claimed. In any case, however, noise as a stress-inducing factor has physical and psychological effects, both momentary and long term. Figure 2.10 shows a range of interference types on the physiological, communication and cognitive levels. It shows clearly that even sounds below 40 dB(A), which are not normally described as noise, are observed at least as altering sleep and thus interfering with the normal cycle of events. The subjective evaluation of the annoyance and/or interference is thus a very individually varied process as clearly shown in the modified stress model (Fig. 2.9) according to SUST AND LAZARUS (1997).

If one considers the findings in the section 2.1.1 concerning the impact of noise on cognitive processes together with the stress reactions illustrated here, one obtains a clear picture of the causal relationship between physiological changes and the

resulting cognitive changes. Even from the aspect of the improvement of the cognitive preparedness for action caused by stress processes, as described by SELYE (1981), this is only related to an increased attentiveness to the stress-inducing factor and not the other processes such as, for instance, solving a mathematical problem or saving information just heard. In this case, the stress reaction is undesirable even if "necessary for survival" from an evolutionary perspective.

2.3.2 Stress processing

Using the occupational science terminology of load and stress this ought to be termed "Reduction or even avoidance of all load factors that affect the work process“. References are constantly made to "Stress management, stress avoidance and antistress training" in the literature relating to this area. KRETSCHMANN (1997) therefore speaks expressly in his training programme about "Vorbeugung beruflicher Überbeanspruchung“ (preventing professional overload) and offers teachers a comprehensive list of behavioural rules for dealing with corresponding teaching situations.
The burnout syndrome is frequently cited as a result of long-term overload in a work situation. BURISCH (1994) describes this syndrome as a result of long-term unmanaged stress processes, usually in conjunction with work situations but also in the general life situations of those affected. He outlines not the attempt to trace these symptoms, which he also describes as the theory of exhaustion, to a single cause, but rather shows various paths that can lead to this condition.
Based on the transactional stress model according to LAZARUS AND LAUNIER (1981) there are, in principle, two possible ways of countering this kind of overload and/or stress reaction in the negative sense (annoyance, distraction):

- Removing the stress-inducing factor
- Improving ones own stress-management resources

The brochure "Stress im Betrieb?" (Stress at work?) (BEERMANN ET AL., 2000) produced by the stress working group of the Bundesanstalt for Arbeitsschutz and Arbeitsmedizin (Federal Institute for Occupational Safety and Health) lists a series of possible points to address. The points are principally divided into two groups, both of which however only indicate possible stress-inducing factors and how to counter them:

- Work organisation and social factors
  Time and deadline pressure, scope of work, social pressure and degree of difficulty,
  problems with colleagues, shift work, etc.
- Ergonomic design deficiencies
  Workplace, resources, working environment

The design possibilities with respect to the workplace, particularly the ergonomics but also the organisation of the work process, are primarily the responsibility of the "employer". In a sub-point relating to measures for reducing stress however, personal stress management is cited as intervention. This is to be applied in conjunction with the second factor from the above stress model, strengthening of ones own resources and/or changing ones evaluation of the stress-inducing factors. These evaluation processes are the subject of the work of KOHLMANN (1990), who considers the

respective coping-strategies that people use in relation to their personalities. This question about coping strategies and personality is also addressed in detail by authors such as SCHAARSCHMIDT AND FISCHER (2001) and SCHMID (2003).
Personal processes for stress management or prevention are not the subjects of this study. They are the domain of psychology and require separate consideration, particularly in the area of schools. The stress-inducing factors in this context, see SCHÖNWÄLDER ET AL. (2003), relate not only to the pure activity of teaching but also to the psycho-social conflicts within an educational establishment, with parents and with problematic pupil groups etc.
With respect to the school workplace for which this investigation was undertaken, there are accordingly three levels of possible intervention in relation to the reduction of possible stress-inducing factors; ergonomics, organisation and teachers' and personal resources.
While the ergonomics and the organisation of the school were questioned in the research project "Lärm in Bildungsstätten“ (noise in educational premises) on which this work is based, the resources of the teachers were not. This personal factor was considered only in the pedagogical intervention study. This data is not used here, however, because it permits no differentiation with regard to the central factor of ergonomics (see section 4.1). The factor of organisation on the other hand can be considered as practically identical for both the schools whose data is used here. In both schools there is a very similar timetable for lessons, and both establishments employ very similar approaches with regard to the social behaviour of the pupils. This leaves the primary factor of workplace-ergonomics as an intervention variable. This is also dealt with in detail in chapter 4.1.
The ergonomic environment variable "noise“ is of great importance according to all findings to date, both on the level of subjective perception by those teachers affected, but also by a series of findings documented in the literature. According to the transactional stress model, the individual factors interact with one another in an infinite loop which is worth analysing. This can only be achieved by considering all the values involved in this process, from the working environment up to and including those people working there. Such an undertaking is subject to constraints of both time and capacity if one obeys the premise of allowing the process under investigation to proceed uninterrupted as far as possible.
In the light of the above constraints it is possible to ask the question:

"What effects does the ergonomic parameter of room acoustics have on the relationship between noise load and stress in respective phases of different teaching?“

3 Research questions and hypotheses

The review in the chapter 2 of the current level of research within the individual disciplines shows very varied progress at times. It also shows, however, the lack of willingness to transgress the boundaries of ones own specialist subject and seek possible links with other disciplines. One exception is occupational science, which has viewed itself as an interdisciplinary subject from the start. However, it has so far investigated exclusively commercial workplace to which the "school workplace“ does not belong. For this reason the school has largely escaped the broader perception of occupational science.
The objective of the present work is to answer the research questions posed based on concrete hypotheses wherein the focus is on the link between the various approaches. The design of the investigation is not intended to obtain new specific findings in the individual subject areas. Rather, at least for this single partial aspect, to obtain a new, fuller picture of schools than is possible from inside the individual disciplines. The reality of schools comprises some very different aspects: different teachers and pupils, very widely differing teaching methods and of course very different ergonomic conditions, e.g. buildings from 1890 to 2000. The approach of BURGERSTEIN AND NETOLITZKY (1902), which views schools as whole entities, has thus far been somewhat unique.
The intention is to answer the research questions in keeping with this tradition using the interdisciplinary approach and to provide as comprehensive a picture as possible of the reality of teaching processes. It is possible that new research questions will emerge within the specialist disciplines involved, which can only be answered within those disciplines.

<u>Research question 1: What relationship exists between noise load in teaching and the ergonomic parameter room acoustics?</u>

One may assume that the relationship, well documented in the literature, between noise level and room acoustics also applies to classrooms and teaching. It must therefore be possible to demonstrate this in several ways. If the room acoustics have a sustained influence on the noise situation in a room as shown in chapter 2.1, it must be possible to show this both within a school with differently equipped classrooms and by means of direct intervention, i.e. changing the room acoustics. This leads to the

1st hypothesis:

A reduced reverberation time in the classrooms leads to a fall both of the basic SPL and of the working SPL in teaching.

The information provided in the literature relating to the distribution of teaching methods and shares of speech of teachers and pupils in teaching are as yet very imprecise. If the noise level in teaching is primarily due to communication, this means that it must be considerably quieter when only the teacher is talking and all pupils are listening. Since this is also related to the method of working, i.e. direct versus pupil-centred teaching methods, this has the following significance the noise level:

2nd hypothesis:

Pupil-centred teaching tends to generate a higher working SPL than direct teaching.

The significance of room acoustics for speech intelligibility is undisputed as shown in all the literature. The room acoustics are particularly significant in relation to teaching discussion, i.e. in phases of intensive communication e.g. differentiated teaching, improving the room acoustics would have a greater effect than during direct teaching phases.

3rd hypothesis:

The noise level is variably influenced in pupil-centred teaching phases by the basic ergonomic condition of room acoustics.

<u>Research question 2: What relationship is there between the stress of the teacher and the ergonomic parameter of room acoustics?</u>

Individual stress is not solely generated by a physical load, as the literature shows, it is far more influenced by psychological load, in which amongst other things ones emotional state plays a very large part. If the acoustic environment contributes significantly to ones well-being in the widest sense, this must be reflected as reduced stress under better conditions.

4th hypothesis:

The stress in teaching and learning depends on the ergonomic basic condition of room acoustics.

Occupational science investigations show a clear relationship between the task, its performance and the resulting load for the person involved. As related to teaching methods in schools, this means that different teaching methods, e.g. due to changed attention requirements, would result in different stress responses.

5th hypothesis:

Stress in the teaching depends on the teaching methods and the course of the day.

If there is a relationship both between the type of task to be achieved as well as the room acoustics and personal stress, this must be shown in the link between the two parameters. Improving the room acoustics therefore ought to lead to a reduction in stress for different teaching methods.

6th hypothesis:

The stress level is influenced to varying degrees in different teaching phases by the ergonomic parameter of room acoustics.

<u>Research question 3: What influence does the ergonomic parameter of room acoustics have in the different working method phases on the relationship of noise load and stress?</u>

Based on the stress theory presented in section 2.3, noise is particularly significant for the triggering of reactions. This relationship can be assumed based on the literature. However, the literature contains no clear relationships between a stress response and the working SPL. In this context reference is generally made to the influence of noise interference. As it is impossible to differentiate between useful signal and interference signal in noise levels measured during teaching, it is not possible to test the relationship in this way. However, it may be an effect of the overall working noise level.

7th hypothesis:

Stress in teaching - measured by the heart rate of the teacher - is proportionally related to the noise of work in teaching.

Stress reactions are greatly influenced by the degree of basic activation to which the daily cycle contributes on one hand and on the other fatigue processes, which may progress more or less evidently, as well as the underlying emotional atmosphere. These are counteracted by phases of restoration, e.g. breaks. If improved room acoustics contribute to a more relaxed working environment then within the context of a specific, comparable teaching situation the stress reaction to noise must be reduced.

8th hypothesis:

The sensitivity to noise of teachers depends on the teaching method and the ergonomic parameter of room acoustics.

4 Methodology and implementation

4.1 Description of data collection

The basis for the present investigation is the data collected by the ISF within the context of the project "Lärm in Bildungsstätten“ (Noise in Educational Premises) (see SCHÖNWÄLDER ET AL., 2004), commissioned by the German Federal Institute for Ocupational Safety and Health (FIOSH) in Dortmund. In this project the work concentrated on the data records from two schools, both of which are distinguished by an overall pedagogical concept including in dealing with noise. Both schools were included in the FIOSH-project as quiet schools and have a good reputation with parents. However the two schools feature very different "starting conditions“:

A) The *Baumberge Schule* in Havixbeck. With 625 pupils and 33 teaching staff this school in its quiet location in this small town near Münster is one of the biggest primary schools in North Rhine-Westphalia. The intake is predominantly middle class with no major social problems. The school building has 25 classrooms and 6 multi-purpose rooms and was built in several phases in 1975, 1977 and 1982. On of the classrooms in the school was acoustically refurbished in April 2004 under the auspices of the association "Lernen statt Lärmen e.V.“. The ISF was involved in this process and therefore data from Havixbeck could be incorporated into the "Lärm in Bildungsstätten“ project report. For several years the school has also been carrying out "social pedagogical training“ with its new intake in order to reduce noise.

B) The *Grundschule in Stichnathstraße* in Bremen. This primary school is situated in a traffic-calmed area with little traffic noise and predominantly featuring blocks of flats. With 400 pupils and 29 teaching staff the Grundschule Stichnathstraße is also one of the larger primary schools in Bremen. Its intake is considered being socially deprived with an estimated 10-15 % receiving social benefits. The school operates a pupil-centred teaching concept and cooperates closely with the department for social services. There is a nursery in the building and a youth centre, the AWO, on the school site. The school building has 22 classrooms, 4 nursery rooms, 1 music room and 1 craft room and was built in 1969. For several years the school has also been carrying out "social pedagogical training“ with its new intake in order to reduce noise.

The data from the FIOSH project is supplemented in the present study by the concurrently recorded physiological reaction data (heart rate) of the teachers. The data now available can be used, thanks to a greatly refined approach, with a far broader question formulation in comparison with the FIOSH project.

While the project data for "Lärm in Bildungsstätten“ – determined by the general problem of "realistic" field research is not representative in a strict methodological sense and possesses limited comparability due to the uniqueness of the recorded situations, great emphasis was placed on a wide spread with respect to type of school, age and social environment in the choice of the recorded teaching units. The present data may therefore be claimed in any case as being of a reliable, descriptive character (see section. 4.3).
The two selected data records each have a particular function for the present study based on their specific qualities. The data record from the Baumberge Schule provides near laboratory-style verifiable basic conditions in that the same teacher

taught the same class in the same classroom with almost the same timetable. Both weeks were free from unusual events. The changed room acoustics therefore mark the only significant difference. The Grundschule Stichnathstraße on the other hand offers a far larger data record which underlines the character of field research with different classes, year groups, teaching staff, subjects and room acoustic conditions. Therefore the Baumberge Schule data record enables the individual questions to be investigated with the necessary exactitude and the relationships itemised in detail. The data obtained in the Grundschule Stichnathstraße does not meet this precondition because it does not relate to directly comparable situations. However, it forms a reliable basis for testing and verifying the results from the Baumberge Schule with restrictions on its general validity in the field.

4.1.1 Room acoustic data collection

Of all ergonomic basic conditions (see section 1.1) of the "school workplace " only the room acoustics are considered since they are the deciding factor on the noise trends in the classroom. The room acoustics are evaluated based on the two parameters of reverberation time *RT* (in the 125 Hz to 8kHz octave bands) and speech intelligibility. The Speech Transmission Index; see section 2.1.2.2, or *STI* is determined from the room impulse response as the measured variable for speech intelligibility according to a process cited by SCHROEDER. The resulting STI based on the measurement process and the analysis characterises only the influence of the room acoustics on the speech intelligibility. Noise interference and the actual speech volume in the room are not directly taken into consideration in the course of the measurement. It would be possible however to calculate this influence retrospectively based on the following relationship (see MOMMERTZ AND GREINER):

$$m(F)^* = m(F) * (1+10^{(-S/Neff)/10})^{-1}$$

The measurements took place according to the specifications given in DIN 3382. The measurement process used was developed by Müller-BBM. In particular the whole measurement process (generation of the measurement signal, absorption of the noise signals reflected within the room [room impulse response], calculation of the measurement results with regard to reverberation time and Speech Transmission Index) was implemented as a software solution and installed on a laptop so that the compact equipment was easy to use in the schools in the investigation.
The computer program generates a sweep from 125 Hz to 8 kHz and 1 sec. duration as a measurement signal, which is radiated omni directionally by a dodecahedron at a height of 1.7 m, at a distance of min. 1.5 m from the nearest wall surface. Recording is carried out by omni directional microphones which were placed at a height of 1.1 m (the ear level of seated children) at 6 different positions in the room. The precise transmission and measurement positions were marked in the measurement monitoring record.
The measured data is augmented by precise room monitoring records, which include the floor plan and details of the wall, floor and ceiling properties plus a furniture diagram. All classrooms were measured when fully occupied, semi-occupied and empty. Two adults were present in the room at all times for the purpose of the measurement. The children present in the room were provided with ear protectors offering approx. 30 dB(A) sound insulation during the measurement.

4.1.2 Measurement of the noise level during the lesson

Noise level meters with the following device-typical features and/or settings were used for the continuous detection of the noise level during the lessons:

Accuracy:	Type 1 (IEC 651)
Measurement range:	30 – 140 dB
Volume range for peak:	43 – 143 dB
Resolution:	0.1 dB
Frequency weighting:	A
Time weighting:	Fast

The devices continuously measure noise level values (L_A) and calculate and save $L_{Aeq,1sec}$ values simultaneously. The L_A values were read into a computer program online and were used to calculate extrapolated values (see section 4.2; for details see SCHÖNWÄLDER ET AL., 2004, p. 22f.).
The noise level was raised in the front third of the classroom for the purpose of increasing the stress on the teacher. The microphones of the measuring instruments were placed at a minimum distance of 1.5 m from the board or the window wall on a tripod such that they were not in the teacher's direct line of speech.

4.1.3 Recording the heart rate during the lesson

For the present study, long term heart rate profiles were produced over the whole "school day" with all lessons and interim break periods both for the teacher from the Baumberge Schule and the twelve teachers of the Grundschule Stichnathstraße. The project "Noise in educational establishments", however, focuses on the morning lessons. That which follows therefore uses only the data from the lessons that took place with the classes under investigation.

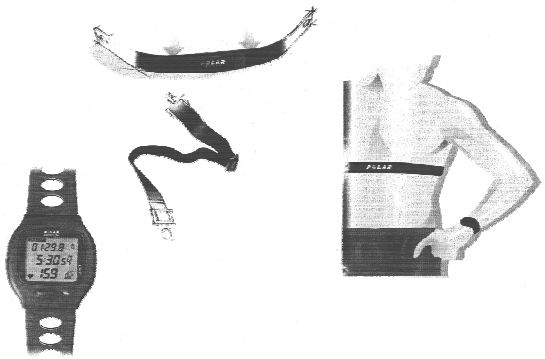


Fig. 4.1 Illustration of the Polar® ECG monitor and heart rate logger system

The heart rate profiles were produced using the measurement systems from the company Polar (see Fig. 4.1). The devices detect heart activity with the aid of a chest strap containing an ECG monitor with a QRS detector. It also acts as a transmitter, emitting a signal when it detects specific heart actions (QRS complexes). This signal is recorded by a receiver which is worn on the wrist. The receiver converts the signal

into a heart rate value and stores it. The stored heart rates are transferred to a PC for analysis after the end of the recording period. Values are saved at 15-second intervals (4 rpm).

4.1.4 Lesson observation

In parallel with the noise level measurements, lesson observations were carried out in the participating classes in both schools. Like the noise level measurements, they took place in lessons throughout the school day over a whole school week in each case. With some deviations from the regular timetable, 154 lessons were monitored at the Grundschule Stichnathstraße and 31 teaching units were monitored for class 2b at the Baumberge Schule (of which 16 were before and 15 after the room acoustic refurbishment).
In each case, basic data was entered on a monitoring sheet for the purpose of characterising the respective teaching day and the lessons before each lesson. After the lesson, the teaching staff added his/her subjective opinion about the noise level, amongst other things, to the monitoring record. Details about the questionnaires can be found in the Appendix of SCHÖNWÄLDER ET AL. (2004), sheets 1-3.
Two observers present in each class carried out the actual lesson observations. Observers had received instruction beforehand with video recordings of lessons. All recordings were transferred a computer in real time for the purpose of relating them later to the other, simultaneously recorded parameters of noise level and heart rate. One observer focused solely on the pedagogical features relevant to this investigation, i.e. the prevailing teaching method in each phase of teaching method and the direction of teaching-related speech. Those activities related to teaching organisation were also noted.
Details of recorded parameters:

Teaching method:	Direct teaching
	Individual work
	Working in pairs
	Working in groups
	Other
Shares of speech:	Teacher to the whole class
	Teacher to individual pupils
	Pupils to the teacher
	Pupils to the whole class
	Pupils to individual pupils
Organisation	Organisational activity

All characteristics were recorded in real time at the start and end of their occurrence at 1 sec. intervals, by pressing a key on a laptop that had been programmed as an event recorder. A second observer was employed in noting other events accompanied by noise on a monitoring sheet. This data is not used in the present investigation, however, and is mentioned only for the sake of completeness.
Since several teams of observers were used in the Grundschule Stichnathstraße, it is not possible to guarantee 100% uniformity and/or comparability of data in this school despite moderation and practice phases before the actual investigation. This makes it difficult to discuss individual data within this school: There may have been some

differences distinguished or incorrectly distinguished between individual teachers due to the different perceptions and/or attributions on the part of the observer. However this problem does not occur in the Baumberge Schule as the same team was used for the entire observation period – another reason for the particular significance and quality of this data record. Also, the two observer teams in the Grundschule Stichnathstraße are distributed evenly throughout the top floor and the ground floor and the potential for error is relativised in a comparison between floors.

A further uncertainty factor should be mentioned. It is not possible to precisely separate individual methods of teaching, either because the methods are mixed or due to the particular arrangements of the teacher concerned (is a short quiet reading phase during which the teacher stands in the centre at the front near the board merely direct, or is it pupil-centred? etc.). It seems sensible therefore to combine individual pupil-centred teaching events to form an overall value (see section 4.2.1.2). In this context one can expect a very good comparability, particularly of the observation value "direct teaching" since the criteria (specified to the observer) were considerably clearer than with the other teaching methods.

One must also mention that the form of data collection selected by the ISF marked a major advance in terms of content as compared to other data records. Whilst previously the relationship between individual teaching methods in teaching were detected solely with respect to one another, the present data record also allows one to read the exact duration of each parameter.

4.2 Data record definition

Four different data pools are available for the purpose of answering the key questions posed here:

- the basic acoustic-ergonomic data from the classroom,
- the noise level that occurred during this lesson in that classroom,
- the pedagogical procedure of the teacher and the teaching employed by him/her
- and the teacher's own physiological reaction, detected by means of the heart rate.

With regard to its incorporation into the workplace model (see. section 2.1) and the hypotheses being checked, however, this data performs a very different function. The room acoustics must be classified as an external factor, the (ergonomic) working conditions, influencing the teaching events. Nevertheless the teaching method in the lesson, as a concrete implementation of the task by the teacher, is also one of the fixed parameter values. Both the noise levels as well as the heart rate, however, depend on the progress of the lesson itself. They are produced, influenced and easily changed by this progress (see section 2.3.1).

Therefore, the two data pool groups are handled differently in the course of the investigation, room acoustics and pedagogical method on the one hand and noise level and heart rate on the other. While the former acts as a filter to isolate and/or to group specific teaching situations and/or periods from the data record and thereby identify different working conditions (see in detail section 4.3), the latter supplies the

subject of the investigation itself; the "consequence". The reference back to the workplace model therefore provides the basis for a detailed analysis of the interdependencies of the detected parameters. In the following therefore the basic room acoustic conditions and the pedagogical teaching methods are described as "filter values“, while noise level and heart rate are classified as "reaction values“.
The two filter values are very different in their significance and their effect: While the static value, room acoustics, describes the "workplace“ of the classroom, the dynamic value of the teaching method represents a parameter for the "work process“ of teaching. Within the context of the FIOSH reserach project "Noise in educational establishments“ (SCHÖNWÄLDER ET AL., 2004) deliberate changes were made to the ergonomic parameters of the workplace, namely to the room acoustics. The pedagogical process on the other hand, was not to change.

4.2.1 Filter values

4.2.1.1 Filter 1: Room acoustic characteristics

The measured values of the room acoustics, Reverberation Time RT and Speech Transmission Index STI, and the data collection have been described earlier in section 4.1.1. For a further investigation it is necessary to collate the measurement results into justified groups. If one forms two equally sized groups with the median of the reverberation time, one obtains a surprisingly even distribution (the choice of classes was made according to pedagogical rather than room acoustic criteria):

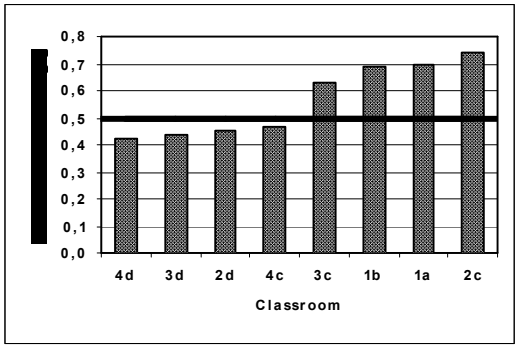


Fig. 4.2 Reverberation times of the classrooms (empty) in the Grundschule Stichnathstraße, divided into ground floor (3c, 1b, 1a, 2c) and top floor (4d, 3d, 2d, 4c)

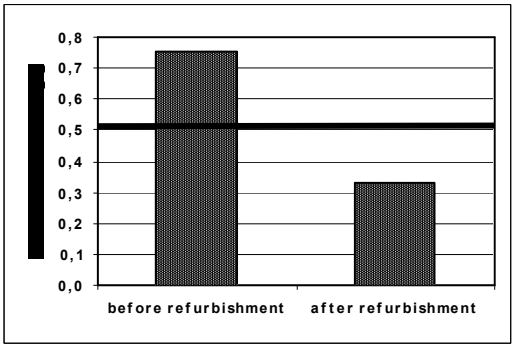


Fig. 4.3 Reverberation time (empty) of the classroom in the Baumberge-schule before and after the acoustic refurbishment

A first glance at the reverberation time measurements in the empty rooms in both schools shows, e.g. a clear difference between the rooms on the ground floor and the top floor in the Grundschule Stichnathstraße (see Fig. 4.2). While the four rooms on the ground floor reveal reverberation times of between 0.6 and 0.8 sec, the reverberation times of the four rooms on the top floor are considerably shorter; between 0.4 and 0.5 sec (see analysis in section 5.1.1). If we observe the two room groups from the perspective of the current literature (MCKENZIE & AIREY, 1999) and/or the latest version of the standard (DIN 18041), the top floor group of rooms uniformly comply with the recommendations and/or specified reverberation times of ≤ 0.5 sec stated therein, while the group of ground floor rooms uniformly exceed this value. The

two measurement results in the Baumberge Schule (see Fig. 4.3) also fall within this schematic. Prior to the refurbishment the average reverberation time considerably exceeded the 0.5-second mark. After the refurbishment however, they fell below the mark by a similar amount.

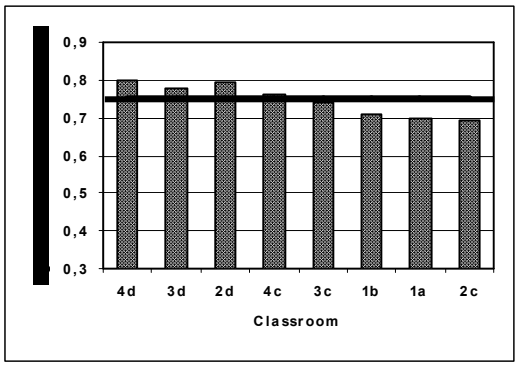


Fig. 4.4 Speech Transmission Index [STI] of the classrooms in the Schule Stichnathstraße, divided into ground floor (3c, 1b, 1a, 2c) and top floor (4d, 3d, 2d, 4c)

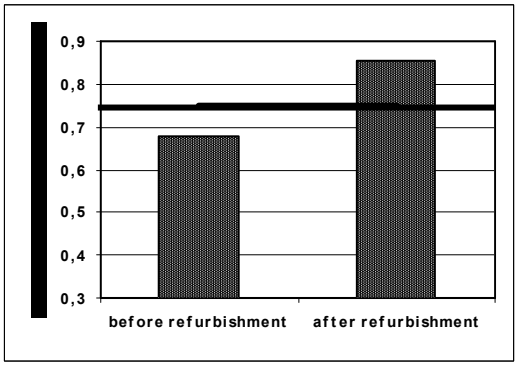


Fig. 4.5 STI before and after the refurbishment of the classroom in the Baumbergeschule

If we check the lesson composition using the median of the Speech Transmission Index STI, we find, also by chance - an equally consistent picture. The dividing line of the two equally-sized and equally distributed groups is precisely 0.75, both in the case of the eight rooms of the Grundschule Stichnathstraße (see Fig. 4.4) as well as in the Baumberge Schule (see Fig. 4.5), i.e. on the dividing line between a rating of "very good“ and only "good“ (speech intelligibility see section 2.1 and/or HOUTGAST AND STEENEKEN). From a room acoustic perspective one can therefore define the following filter parameters for the subsequent analysis:

Reverberation time RT	< 0.5 s
	> 0.5 s
Speech Transmission Index STI	> 0.75
	< 0.75

The rooms involved in the project can thereby be divided into following equal-sized groups:

RT < 0.5 s	STI > 0.75	Hvx: Class 2bs; Stchn: Classes 2c, 1a, 1b, 2c
RT > 0.5 s	STI < 0.75	Hvx: Class 2b; Stchn: Class 4c, 2d, 3d, 4d

4.2.1.2 Filter 2: Pedagogical features

The pedagogical approach, the type of teaching and not least the communication scenario in the classroom naturally play a significant role in an investigation into the acoustic working conditions. Therefore, if we are to give credence to the current discussion (see section 1.2) about "modern teaching“, the events in classrooms have changed fundamentally in recent decades. The interplay and relationship of "direct“ and "pupil centred“ teaching methods is consequently a elementary filter value when it comes to answering the key questions. The precondition for a practical approach to these pedagogical features is therefore both a time- and content-based lesson composition which enables individual data to be used for further analysis. The task consists of developing a content-based definition and the possibility of assigning working phases within lessons to timed periods in the sense of "predominantly direct“ or "typically pupil-centred“.

4.2.1.2.1 The time-dependent lesson composition – "> 50 %“ vs. "< 50 %“

The teaching method was originally detected on a 1 sec. interval basis (see 4.1.5). Along with the 45 min. lessons, a 5 min. interval is selected for further analysis, which divides the lessons into 9 equal units. (A random shorter pattern of approx. 1-minute intervals was tested, but revealed no new findings – the original data was not especially suited to very short time units.) The individual observation criteria are then combined over the period to be analysed and thereby represent the overall duration of each teaching method within 1sec. time slices. For the purposes of further analysis it is necessary to check whether dichotomising the categories reliably reflects the actual distribution of the working methods. For a more accurate definition of the duration of different teaching methods, in this case for instance the "direct teaching“ (dT) category in the Baumberge Schule, is hereafter represented via a frequency distribution of the time interval.

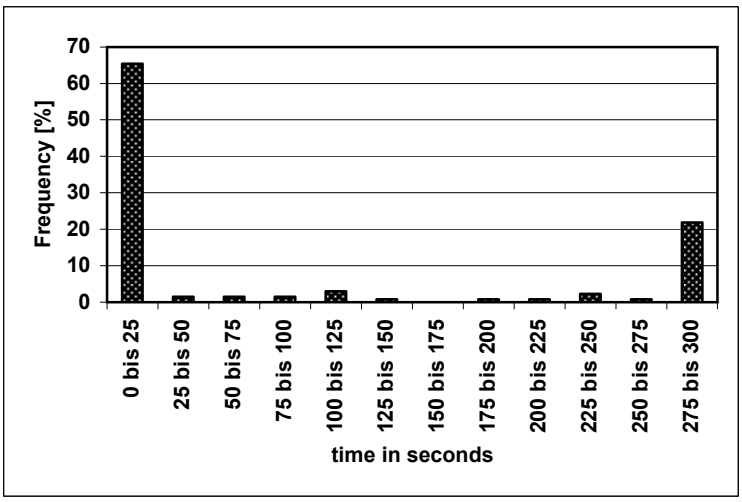


Fig. 4.6 Frequency distribution of the percentages of direct teaching time in 5-min time units, original data record – represented in nine categories; Baumberge Schule (see 4.1.5)

The distribution pattern for the class shown in Figure 4.6 can also be found in all other data records and is typical not only for direct teaching but also for all other

teaching methods. The values between the two peripheral groups which would indicate transitional circumstances were equally seldom. It would appear to be a good idea to try to reduce the classes further.
If one creates three classes one gets the same picture. The middle group is very sparsely populated, less than 5 %. The clear differences in both peripheral classes is retained even if divided into three (see. Fig. 4.7).

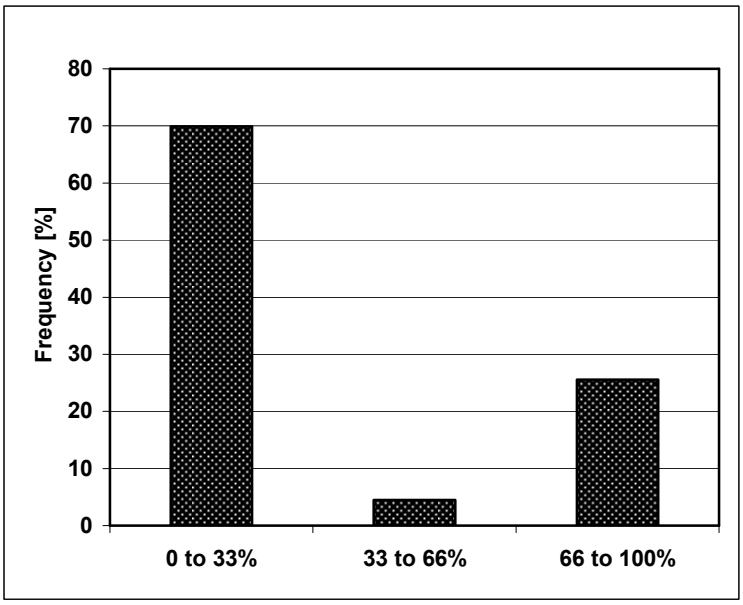


Fig. 4.7 Frequency distribution of the percentages of direct teaching time in 5-min time units, represented in three categories; Baumberge Schule

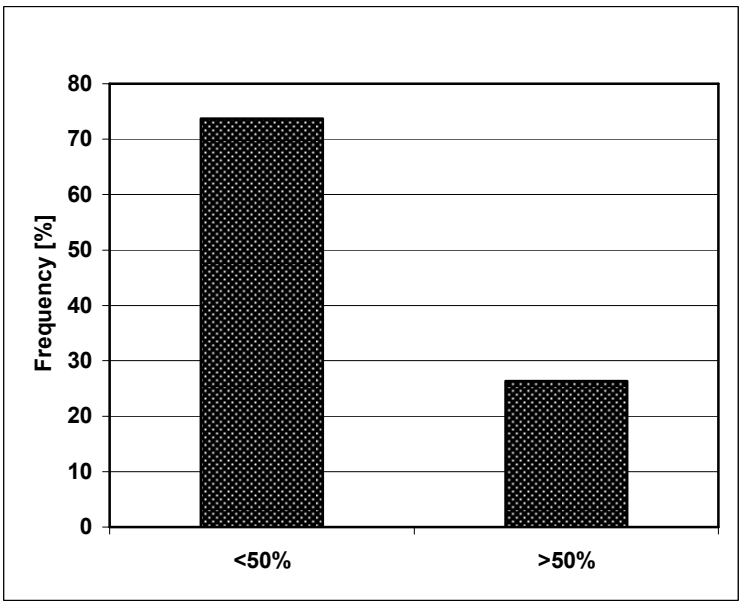


Fig. 4.8 Frequency distribution of the percentages of time of direct teaching in 5-min time units, original data record – represented in two categories; Baumberge Schule

Figure 4.8 enables us to conclude that the distribution does not alter, even in a two-category configuration. It is therefore possible to speak of a time unit with "little“ (< 50 %) and/or "predominantly“ (> 50 %) "direct teaching“ (dT). For future

observations this gives a simple and equally well-founded and reliable characterisation of the working method with constant reference to the time interval.
To check these results, the lesson breakdown is carried out once again on two classes from the Grundschule Stichnathstraße whose teachers employed different working methods during the investigative period (Fig. 4.9 – 4.11). The central question is whether the dichotomisation and the associated extreme simplification of the data record retains the original frequency distribution of direct teaching in both cases.

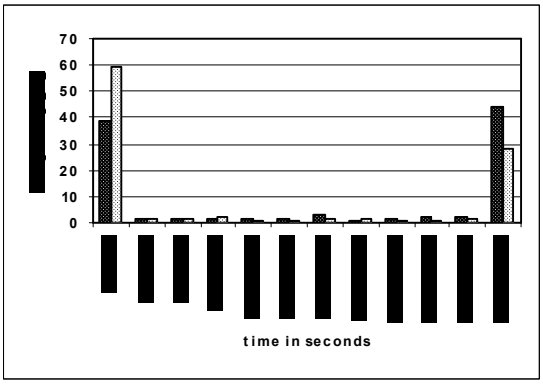


Fig. 4.9 Frequency distribution of the percentages of direct teaching time in 5-min time units, original data record – represented in nine categories; Grundschule Stichnathstraße (see 4.1.5); in comparison: classes 1a (■) and 1b (□)

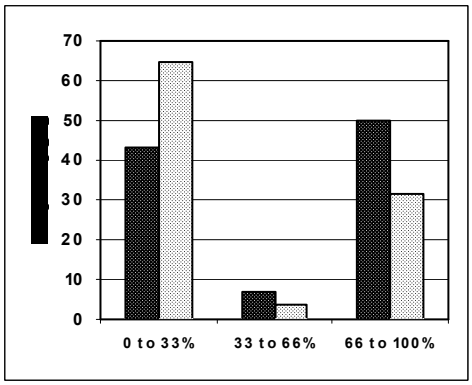


Fig. 4.10 Frequency distribution of the percentages of time of direct teaching in 5-min time units, original data record – represented in three categories; Grundschule Stichnathstraße; in comparison: classes 1a (■) and 1b (□)

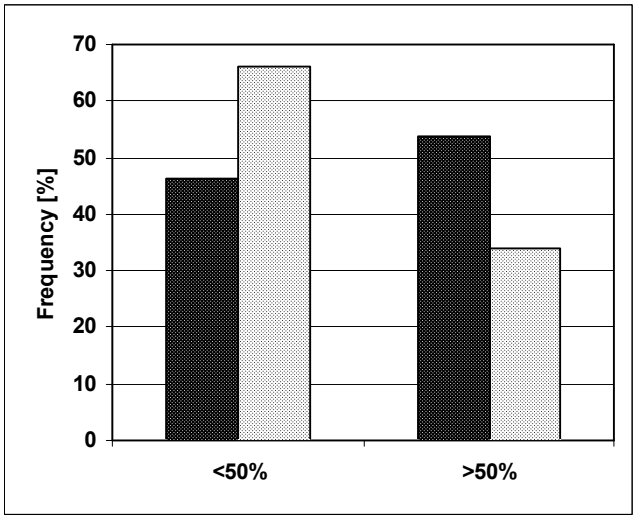


Fig. 4.11 Frequency distribution of the percentages of direct teaching time in 5-min time units, represented in two categories; Grundschule Stichnathstraße; in comparison: classes 1a (■) and 1b (□)

The results show that the dichotomisation retains the original frequency distribution of the temporal percentages of direct teaching in all three cases. It therefore represents

a reliable process for further data analysis. Further series of tests have also revealed that the dichotomous lesson composition at the 50% mark can be transferred equally reliably to other teaching methods.

4.2.1.2.2 Content-based lesson composition – "dT“ and "scT“

There was no general "pupil-centred teaching“ category in the actual observation schema. Instead, ER (event recorder) data was requested for actual methods such as "Individual work“ (WI), "Working in groups“ (WG) and "Working in pairs“ (WP) (see 4.1.5). For the sake of a clear picture and unambiguous attributions it nevertheless seems to make sense to group this individual data into a broader raster for further operationalising. This is also because it is often not as easy to separate teaching methods in practice as it might seem in the teaching manual. In addition, many of the monitors found differentiating between working in groups, working in pairs and other organisational methods relatively difficult in practice. This led to the problem outlined in 4.1 of the occasional variation in the behaviour of observers in the individual schools in the investigation. However "direct teaching“ periods were relatively clearly delineated. Direct teaching referred to periods when the attention of the whole class was directed at the teacher and the pupils' task was therefore to receive. If therefore the monitoring data with regard to the value "direct teaching“ (dT) can be evaluated as reliably it becomes justifiably possible to subsume all those teaching methods that fall outside the parameter of direct teaching, in which pupils are working without being focused on the teacher (group value 1-n) into to one group; "student-centred teaching“ (scT).

$$scT = WG + WP + WI$$

(The "organisation“ value can be disregarded in the case of this group configuration since it was detected in parallel, i.e. not alternatively, to the other teaching methods and does not alter the relationship.)

A direct comparison (Fig. 4.12 and 4.13) provides a surprising impression at first glance. The overall comparison of the combined data group "scT“ with direct teaching reveals a different ratio than that given by the individual parameters WG, WP and WI in the individual comparison. In fact the cumulative values offer a considerably more realistic view of the actual teaching events than the individual values. Because these are calculated from the original data rather than simply representing the arithmetic average of the individual classes, the original relationship between direct and pupil-centred methods re-emerges.

One example: if a 5 min. lesson interval in the original data record consisted of 30 % WI, 30 % WP, 30 % WG and 40 % dT, i.e. obviously comprising predominantly pupil-centred teaching, the time slice would nevertheless be classified as direct teaching in the individual observation every time because the value for dT is greater than the respective individual values. Combining the individual parameters to form a single group "scT“ corrects this statistical error and attributes the time slice correctly to pupil-centred teaching.

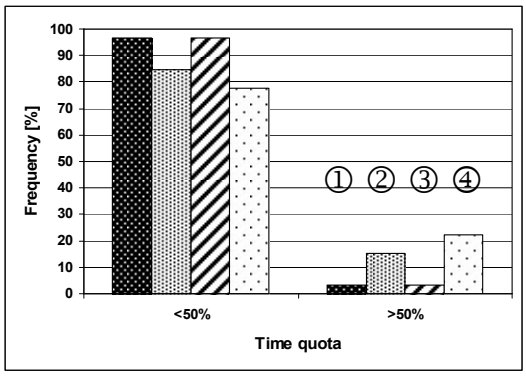


Fig. 4.12 Comparison of the categories WI (1), WP (2), WG (3) and scT (4) each in the time attributions of < 50 % and > 50 %; in this case: Baumberge Schule data basis

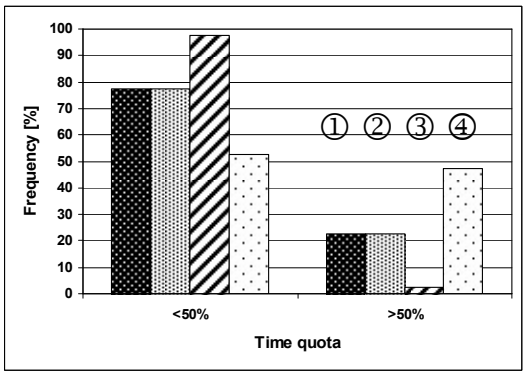


Fig. 4.13 Comparison of the categories WI (1), WP (2), WG (3) and scT (4) with respective time allocations of < 50 % and > 50 %; in this case: Stichnathstraße data basis

From a pedagogical perspective, it is justifiably possible in a further analysis to break down the teaching methods monitored during the project period into the following filter parameters:

1) Time quota spent on a particular teaching method in a lesson: < 50 %
> 50 %

2) Content-based definition of the teaching method AF: dT(direct teaching)
scT (student centred teaching)

4.2.1.3 <u>Filter combinations</u>

To answer the key questions posed requires a combined observation of room acoustic and pedagogical aspects commencing at a pre-determined time. At the heart of this exercise is the interest in the behaviour of the reaction values of noise level and heart rate during a specific teaching method with regard to a selected acoustic-ergonomic parameter. The workplace model and the associated connections at the start of this chapter in fact already specify this kind of combination of filter values.

4.2.2 Reaction values

If in the terms of occupational science the ergonomics of a workplace – the classroom in the present project – are altered by an intervention measure, one requires one or more reaction values, on the basis of whose changes the effect of the intervention can be measured and also evaluated. For example, the installation of better lighting can be obviously measured on the basis of the luminous intensity at the workplace but also on the basis of the changes to the work rate or physiological changes in the workers, e. g. fatigue. The present question foregrounds two parameters whose relatedness is assumed and which ought to be influenced by a deliberate intervention.

As already outlined in section 4.2.1, the "classroom“ workplace can be characterised firstly by the static value of room acoustics and secondly by the dynamic value of the teaching method. What impact do these two ergonomic conditions therefore have on the work process, in this case the teaching?

4.2.2.1 Noise level

As demonstrated in section 2.1 there is a direct relationship between the noise level in a room and its room acoustic properties, i.e. this level is an indicator, provided that the source of the noise does not change, for the effectiveness or an intervention measure. The noise level however is also an indicator for the effects of communication and/or work processes.
Which of the noise level values in a classroom are relevant for the evaluation and/or which should be used to describe the effect of an intervention? While one might decide "the quieter the teaching the better the learning environment“, this nevertheless contradicts to a certain extent the expectations of a teaching situation. Teaching is associated with the expectation that a series of individuals is working together either alone, within the group or in any form in which this work comprises both receiving and producing, but in any case involving a minimum of vocal communication. In addition there is an absolutely essential percentage of noise caused by bodily functions such as breathing and physical movement.
From the almost continuous noise level record therefore there are two significant parameters which also align very closely to teachers' subjective descriptions of the noise situation:

- *Basic SPL*: this term refers to the general basic noise level in a fully occupied class over a defined time period. For this we use the standardised acoustic measurement of L_{A95}, which represents the noise level that is exceeded 95 % of the time. This value therefore describes the basic noise situation significantly better than, e.g. the minimum level, which may occur purely accidentally (see RITTERSTAEDT, PAULSEN AND KASKA, 1980).
- *Working SPL*: the noise level parameter describing a working situation corresponds to the level value emitted energetically over the period, the average level $L_{Aeq,Time}$.

Based on the need to analyse different time slices, from the overall 45 min lesson down to short working phases of 5 min, there is a requirement for noise level parameters that characterise these time slices (see Table 4.1). The two parameters outlined above describe the noise trend for that working situation for both the smaller as well as the larger time units. Both parameters are calculated from the continuously determined level $L_{Aeq,1sec}$.

Table 4.1 Parameters for basic and working SPL

Time span	*Parameter*	
1 sec	$L_{Aeq,1sec}$	Average noise level value over 1 sec.
5 min	$L_{Aeq,5min}$	*"Working SPL"* Average noise level value over 5 sec.
	$L_{A95,5min}$	*"Basic SPL"* Is exceeded for 95 % of the time
1 lesson	$L_{Aeq,\ 45min}$	*"Working SPL"* Average noise level value over 1 lesson
	$L_{A95,\ 45min}$	*"Basic SPL"* Is exceeded for 95 % of the time

These parameters can also be used for any other time interval.

4.2.2.2 Heart rate

The impact of intervention measures at a workplace naturally also affects those people working there. As well as the option of subjective questioning as to state of mind or about the experiencing of a change, the heart rate is used as an indicator for stress (see section 2.2). A deliberate influencing of the heart rate, e.g. in the context of relaxation through self-hypnosis, is out of the question in a normal teaching situation. This therefore provides an objective measurement for stress.
In analogy to the reaction value "noise level" the parameter of heart rate can be broken down into two parts, a slowly changing *tonic* part and a *phasic* part, which rapidly adjusts to the actual load (see SCHANDRY).

- **Basic activation**: the basic activation refers to the tonic part. It changes, for example, throughout the day but possibly also during a lesson due, for example, to the fatigue process. The basic level of activity is determined as a minimum heart rate value within a defined time interval. Recording the heart rate every 15 sec. avoids the necessity for any mediation to eliminate respiratory arrhythmia. The basic value signals the prevailing basal activation level during the observed period (the degree of psychophysical "excitation").
- **Stress**: The variation of heart rate in response to the actual stress is called the phasic part and is obtained from the average of the heart rate values measured every 15sec. over the selected time interval.

The time slices to be analysed are subject to the same noise level rules as given previously in section 4.2.2.1.

4.3 Methodology: Filtering – Grouping – Analysis

The present data record represents a map of the real work situation. It was not collected within the context of the kind of properly proportioned investigation design that is to be found in laboratory investigations and it can be analysed only with the techniques of descriptive statistics. The stringent design of an intervention study in which precisely one parameter is varied cannot be applied to this kind of field study. It is not possible to compare two consecutive situations because the effect of interference variables can be limited but never eliminated. In section 4.1 of this chapter information was given about the selected data record, also outlining the particular features of the two schools; the Baumberge-Schule and Grundschule Stichnathstraße.
In practice there are usually two methods used for the data analysis in order to counter these difficulties in verification. The first is to use the largest possible quantity of representative data records and the second is to observe situations with maximum concurrence. The two selected data records respectively meet one of these preconditions. The data from the Grundschule Stichnathstraße covers eight classes while the data from the Baumberge Schule covers one class which was observed for one week before and one week after the intervention measure.
Both schools provide the following data, described several times already, for the purposes of evaluation.

- Noise level, 1sec. intervals
- Heart rate, 15sec. intervals
- Lesson observation (11 parameters), 1sec. intervals.

This gives a total data record per lesson (45 min) of:

- 180 heart rate values
- 2,700 SPL values
- 8,100 values for the shares of speech of the teaching staff
- 5,400 values for the shares of speech of the students
- 13,500 values relating to teaching methods

This permits a 1sec. time interval for the analysis, excluding the heart rate data which is recorded every 15 sec. Shorter time slices for the heart rate monitoring for the purposes of stress analysis in field studies relating to occupational science questions are not usually set due to difficulties in verifying the situation (see SCHÖNWÄLDER ET AL., 2001).
A verifiable handling of this very complex data record of a single lesson or a day of lessons generally requires a three-step approach. The first step is to filter the data records using the parameters defined so far. The second step involves breaking down the data records into time units which are defined on the basis of the relevant key questions. The final descriptive data analysis is carried out on this basis.

4.3.1 Filtering

As outlined above in 4.2.1 the data records are sorted according to both room acoustic as well as pedagogical features for the purposes of comparison. We proceed from the workplace model which has rarely been applied in this complexity, and when it has been, then predominantly in office workplaces. Little is generally spoken about the ergonomics of schools. *Filtering* the data records permits the isolation of individual effects and subsequently the combined effects of the individual

influential values. In this case two reactions values must be taken into consideration, working noise and stress. A basic filter consists of the choice of data records that are to be analysed. This process however is not referred to as filtering in this case but rather a pre-selection. It relates to the exclusion of data which does not contribute to answering the questions posed here, e.g. lessons carried out under unusual conditions, e.g. sport or music lessons that do not take place in the actual classrooms, or lessons with incomplete data records, e.g. noise level data without lesson observation.

4.3.2 Grouping

The basic question with regard to the grouping of data concerns the time slices to be applied. It is necessary to define time slices within which the respective data records can be related to one another within the context of each question. These time slices are formed primarily on the basis of the time structure which regulates the working rhythm of the school. The first important time interval is undisputedly the lesson itself. To be able to analyse the teaching process, however, the individual lessons must be broken down into smaller time units. In the following, the 5 min time interval is used. The lessons are thus divided into nine equal parts. Justification for this time window comes from several sources. In mathematics, a polynomial approximation to the third or fifth degree is used to describe the sequences of events that we find in schools, which is quite feasible with nine sampling points (see ULLRICH, 1981). One suspects that shorter time slices will deliver no new information (see 4.2.2). An analysis of the noise level in teaching at 5min. time slices allows both the calculation of the average value $L_{Aeq,5min}$ as well as of the basic SPL L_{A95}. The 300 individual $L_{Aeq,1sec}$ values provide a more reliable basis for determining this 95% level. The 5min. time window has also been proven appropriate in determining a basic activation from the heart rate data (see SCHÖNWÄLDER ET AL., 2003, TIESLER ET AL., 2002).
It also shows the significance of the high level of temporal resolution with which the data was originally obtained. As far as we can tell the time slices imposed here allow a teaching-related data evaluation not only on a lesson basis but also on the basis of shorter time units. This process enables, for example, an internal analysis of lesson phases which are dominated by a particular teaching method.

4.3.3 Analysis

The analysis of the selected data after filtering and grouping is generally descriptive. The data is not suited even for random comparisons. It is often based on the very different data quantities which remain after filtering and grouping and often on very different data structures. One thinks in this case of the observation data. Analysis of the frequency distributions in particular and pure average value comparisons are two methods used for the comparison of two data groups. This is generally more reliable in the given context, particularly if, as is often the case with recordings of heart rate or noise level, the data is not normally distributed. At some points, attempts are made to represent the relationship between two values by means of linear regression in order at least to illustrate trends. However, the stringent statistical preconditions required for this (see LIENERT) are not present.
In the context of the noise level analysis it is necessary to point out a problem concerning averages. If for example the average level of noise is calculated for a lesson or any time interval, it refers to an energetic average, as is standard in noise research. The averaging is first carried out at the sound intensity level and is then

converted into the logarithmic level representation. Mathematical averaging is used, however, when comparing different time slices and/or situations. In this case the result therefore does not include an “Overall average level” from all 1sec. values of these time slices but is actually the value mathematically determined from the original average levels of the individual time slices.
None of the standard statistical significance tests are used in the course of the data analysis. The key characteristic of this approach, however, lies in the fact that it can provide a very precisely timed view of the work process as it is dominated by external factors.

5 Data analysis

5.1 Internal analysis of filter parameters

5.1.1 Filter "Room acoustics" – Internal analysis of the filter parameters RT and STI

The rooms involved in the investigation have few outstanding features with regard to their basic room acoustic data. The reverberation times in the 8 monitored rooms in the Grundschule Stichnathstraße and in the classroom in the Baumberge Schule varied – with a remarkable range of up to 0.4 s – in the order of magnitude which earlier investigations (see e. g. MOMMERTZ or MASUHR) stated for classrooms of a normal cubic size and furnishing. There were no greater-than-average reverberation times of over 1 s (such as in RUHE, 2003b, or SCHÖNWÄLDER ET AL., 2004) measured in the present data record. Figures 5.1 and 5.2 provide an overview of the average reverberation times of all evaluated rooms when respectively empty, half-full and full. The averaging took into consideration the whole of the speech-relevant frequency range with 125 Hz to 8 kHz octave bands. The individual frequency-related results and the room data can be found the in table in Appendix A.

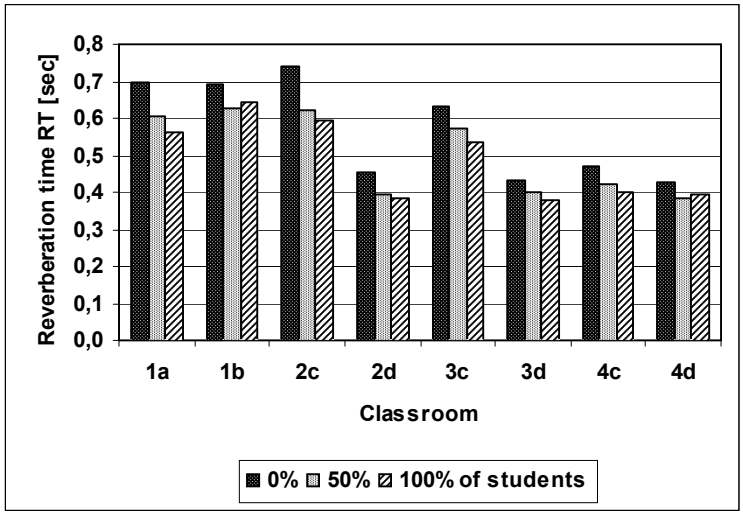


Fig. 5.1 Room acoustic balance for the Grundschule Stichnathstraße; average reverberation times measured in empty, half-full and fully-occupied room

In a room acoustic evaluation, approximately according to the latest version DIN 18041, the classrooms in the Stichnathstraße fell into two distinct groups. The rooms on the top floor of the classes 2d, 3d, 4c and 4d meet the current specifications with reverberation times under 0.5 s, while the classrooms on the ground floor, 1a, 1b, 2c and 3c, exceed the limit (see section 4.2.1.1). Within the liberal terms of the standard (without taking individual cases into account i.e. without taking into consideration children with learning difficulties, children not learning in their mother tongue or foreign language lessons) the average reverberation times of the fully-occupied classrooms 1a and 3c still fell within the tolerance range.

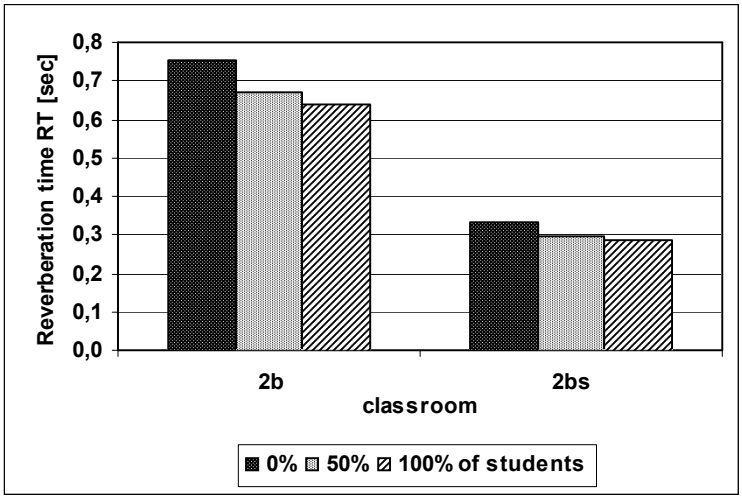


Fig. 5.2 Room acoustic balance for the Baumberge Schule; average reverberation times measured in empty, half-full and fully-occupied room

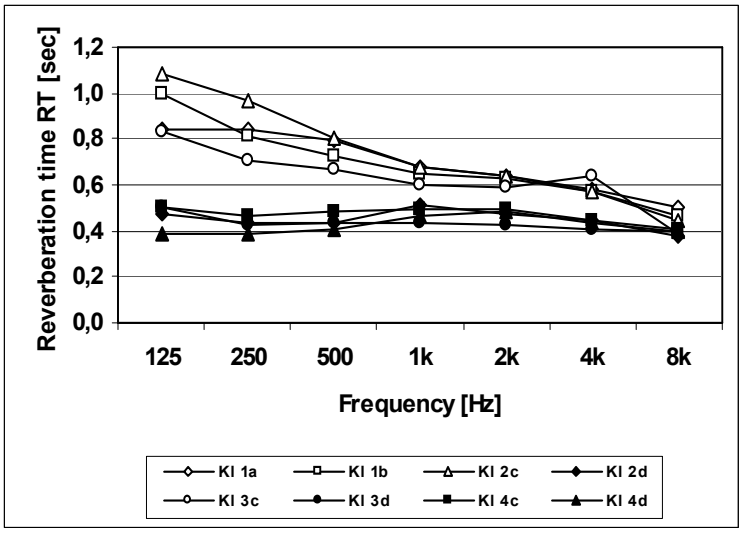


Fig. 5.3 Frequency-dependent reverberation time of the classrooms in the Grundschule Stichnathstraße when empty

The frequency-dependent analysis reveals a further difference between the two groups of rooms. The rooms on the top floor with the shorter reverberation time from 125 Hz to 8 kHz reveal a very linear, even frequency trend, while the classrooms on the ground floor are all characterised by a clear rise in the reverberation time at the low frequency band (Fig. 5.3). At the same time there is once again revealed within the (architecturally very similar) rooms an astounding breadth of variation between 0.8 and 1.1 s in the 125 Hz octave band. This difference cannot be simply attributed to the different room volumes (between 180 m³; cl. 2C and 230 m³; cl. 1b). There is no mutual dependency. Even when full however, classrooms 1a and 3c, at least within the octave band 125 Hz, are still above the specifications of DIN 18041 (Fig. 5.4).

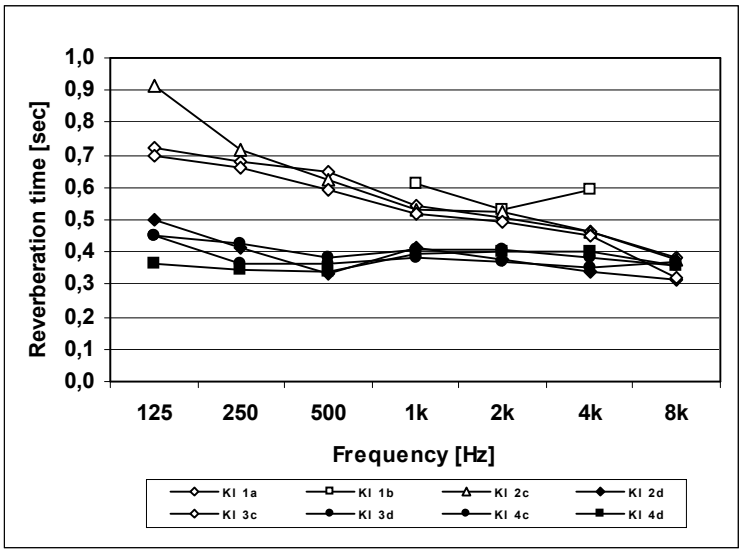


Fig. 5.4 Frequency-dependent reverberation time of the classrooms in the Grundschule Stichnathstraße when fully occupied

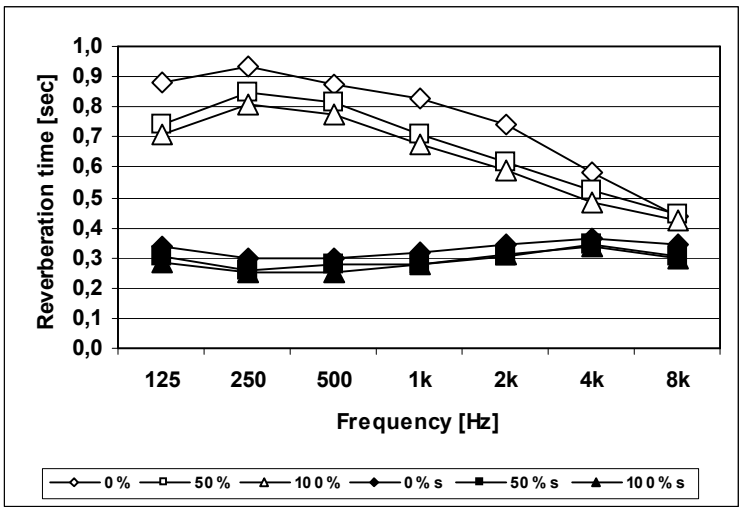


Fig. 5.5 Frequency-dependent reverberation time of the classroom in the Baumberge Schule before (□) and after (■) the refurbishment when empty, half-full and fully occupied

The frequency-dependent observation of the reverberation time in the classroom in the Baumberge Schule gives a similar picture. Here again the measurement in the original state with an average reverberation time of 0.75 s. when empty and 0.65 s. in the room when full produced no catastrophic but equally no very good results with a clear rise in the reverberation time towards the average and low frequencies (Fig. 5.5). Great attention was paid again to creating a linear reverberation time during the refurbishment. As expected, since the classroom in the Baumberge Schule with its very short reverberation time of 0.35 s. was very heavily attenuated by the refurbishment, it responds hardly at all to the room occupancy after the renovation. The room's acoustic measurement data remains largely independent of the number of people present in the room. In general the room occupancy did not affect the room acoustic data as much as expected. In fact the reduction of the reverberation time by the additional absorption of the pupils – in relation to the situation at the outset - was

generally only in the region of two decimal places. Figure 5.6 shows that the reduction of the reverberation time did not reach a significant order of magnitude of over 0.1 s until a reverberation time in the empty classroom reached around 0.7 s and more.

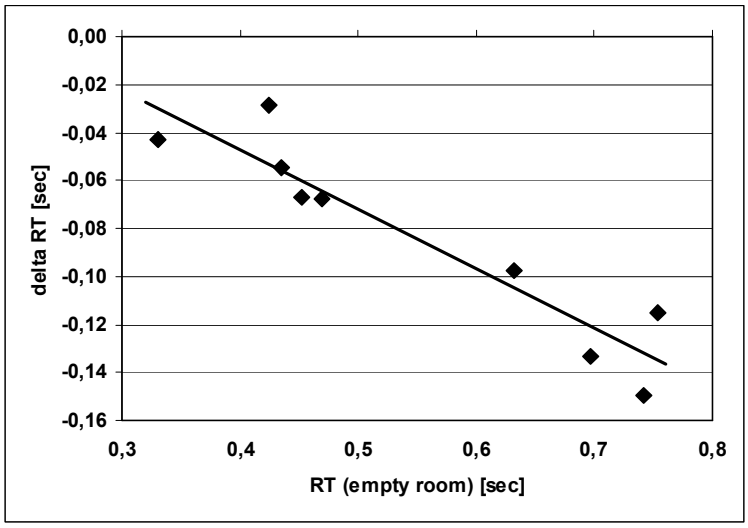


Fig. 5.6 Changing the reverberation time by filling the classrooms with pupils in comparison with the classrooms when empty
delta RT[s] = 0.052 – 0.249 * RT[s]; r = 0.94

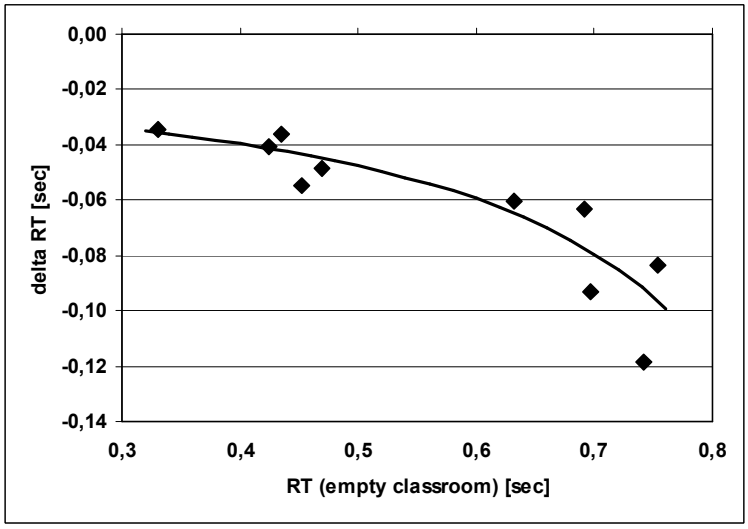


Fig. 5.7 Changing the reverberation time by half filling the classrooms with pupils in comparison with the classrooms when empty
delta RT[s] = 1/(-42.042 + 42.059) * RT [s]; r = 0.93

However on second glance this relationship was not as linear as assumed. In the analysis of the effect of just 50 % room occupancy it emerged that with less density of pupils in the classrooms the interdependency between original reverberation time and its reduction rose as the initial value rose. In rooms with an initial value of below 0.5 s the changes were still only within ranges of less than 0.05 s and therefore already within the order of magnitude of normal measurement tolerances (Fig. 5.7).

With the direct comparison of the numerical values however it also became clear that a significantly greater proportion of the changes due to occupancy shown in Figure 5.1 of the reverberation time could be traced to the first half of the pupils. In fact on closer examination it was clear that while the increase in occupancy from half to all the pupils delivered the expected further reduction in the reverberation time, the order of magnitude was negligible, being around 0.01 to 0.04 s. It is not practical to construct a relationship based on these minor changes and the original situation with this data (Fig. 5.8). Further analysis of the results is also prohibited due to the lack of accuracy of the measurements which are to be taken at the same level at least and which endow the data with a rather accidental character.

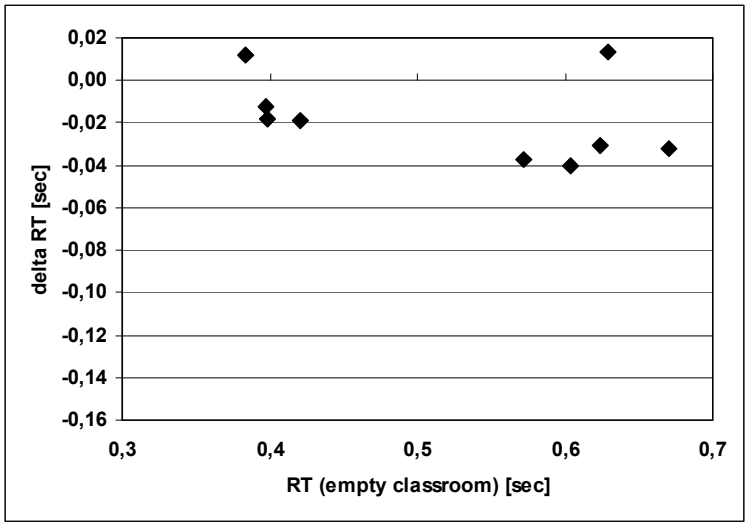


Fig. 5.8 Changing the reverberation time by filling the classrooms with pupils in comparison with the classrooms when half-full
There is no evident relationship.

Nevertheless this first analysis awakens sufficient interest for a more precise, predominantly frequency-dependent question as to the equivalent absorption surface of pupils of primary school age in the furnished classroom. The data basis still includes those classrooms involved in the investigation in the Grundschule Stichnathstraße and the Baumberge Schule when empty, half-full and fully occupied. Nevertheless, in that which follows the measurements from Class 1b of the Stichnathstraße and from the refurbished classroom 2bs of the Baumberge Schule are sometimes not taken into consideration because in one case the measurements were inaccurate in some of the octave bands and in the other case due to the severely attenuated room acoustics, the smallest deviations within the unsafe measurement range of the measured reverberation time lead to excessive changes in the back-calculated absorption surface.
If one calculates the additional absorption surface generated by the pupils from the measurements using the Sabine's formula - taking into account all the uncertainties associated with this (see section 2.1.1) – the dependency on the density of the occupation as mentioned above is evident once again. Figures 5.9 and 5.10 show the differences both in the case of the overall-absorption surface which is generated by the pupils in the classroom as well as for the absorption surface per individual pupil. While the latter is 0.41 m² in relation to the frequency athe centre with full occupancy, i.e. with some 2.2 to 2.6 m² floor area per pupil, it is considerably higher

at an average 0.56 m² per pupil when the classroom is only half-full, i.e. approx. 4.5 to 5.3 m² floor space per pupil.

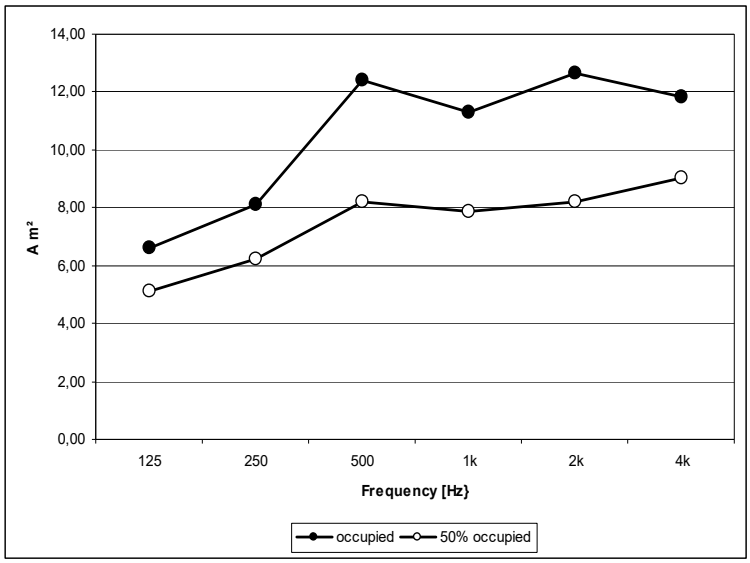


Fig. 5.9 Equivalent absorption surface by pupils per class at full and half-full occupancy (average value of Grundschule Stichnathstraße + Baumberge Schule (excluding 2bs))

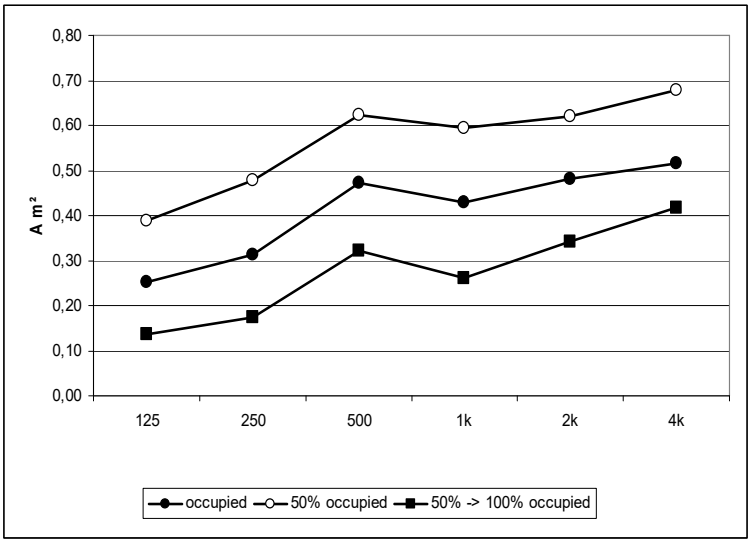


Fig. 5.10 Equivalent absorption surface per pupil at different occupancy densities (average of Grundschule Stichnathstraße + Baumberge Schule (excluding 2bs))

It is once again obvious how little the second half of the room occupancy contributes. With a mathematically derived absorption surface of an average of only 0.28 m² per pupil, thee pupils contribute considerably less to the result. Since obviously all pupils contribute similar physical absorption characteristics, the reason for this divergence would require further investigation. It might be worth considering, for example, a closer observation of the pupil as a scattering body and the changing distributing body density that accompanies occupancy. It might also be worth considering the question of room diffusion in classrooms. (However, attention should be paid to the

fact that the measurements in the half-full rooms were taken with as even a distribution of the children as possible.)

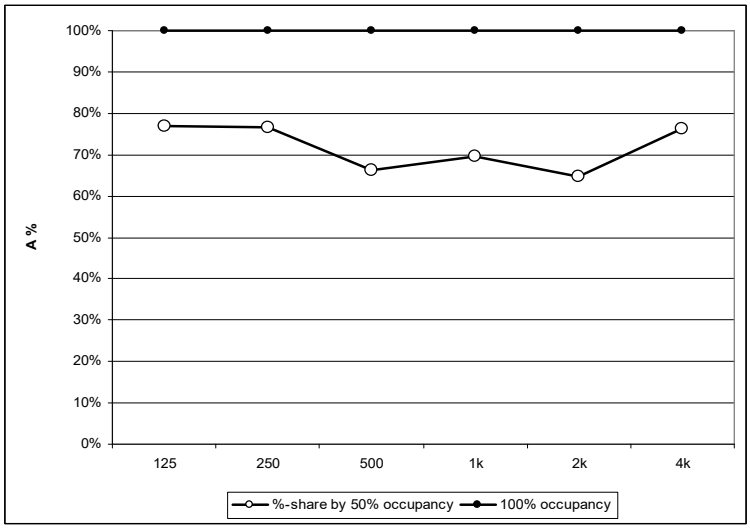


Fig. 5.11 Relative absorption surface of pupils per class – in comparison: full and half-full occupancy (average value of Grundschule Stichnathstraße + Baumberge Schule (excluding 2bs))

It is clear in any case that the maximum achievable absorption effect of pupils was practically exhausted when the classrooms in the present investigation were half-full. The second half of the pupils hardly influenced the rooms in the technically distinguishable measurement range.
If one looks at the overall-absorption surface created by pupils in the room (100 %) it becomes clear that in relation to the octave band an average of approx. 70 % of this surface is already present with the first 12 to 15 pupils in the room (Fig. 5.11).
The final surprise is the unexpectedly high acoustic "efficiency" of the primary school children in the 125 Hz octave band. With absorption values of 0.3 to 0.4 m² per pupil (Fig. 5.10) this is considerably higher than the traditional data provided in the specialist literature and/or the latest version of DIN 18041. In this case all the measurements were carried out during the spring (March to May) and the children were dressed "averagely warmly" for this time of year.
In the statistical averaging the absorption values of the first year pupils do not differ from those of their colleagues in year four. The values closely match those figures recently presented by MOMMERTZ on the broader basis of the overall FIOSH project "Lärm in Bildungsstätten" (Noise in Educational Premises) (MOMMERTZ, 2005), which also included pupils in the first years of secondary and high school. However MOMMERTZ has not published an age-related analysis. To figure out the extent to which the numerical values vary with the age (and therefore the size) or even the clothes of the pupils could be a job for civil engineering, for instance using more precise measurements in the reverberation chamber. At least in the case of older young people and/or young adults (last years of secondary and high school) one would be justified in expected clearly different results. The absorption values of primary school children certainly do not provide a helpful basis for this pupil group.

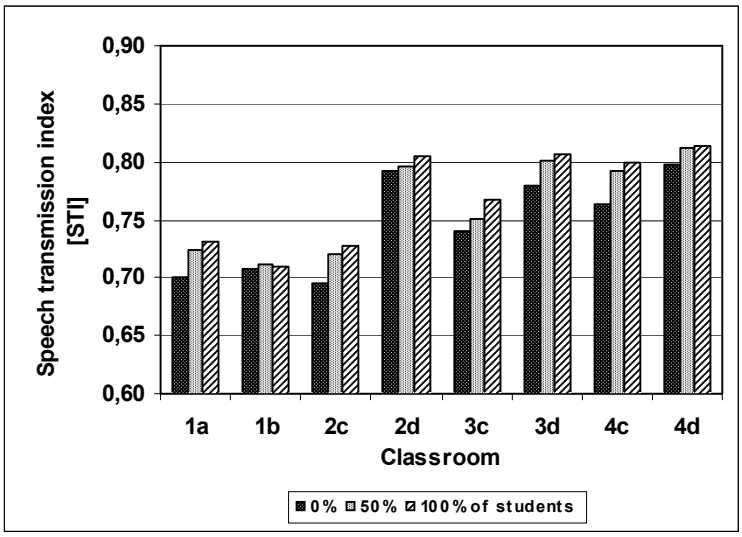


Fig. 5.12 Speech Transmission Index STI in the classrooms at the Grundschule Stichnathstraße, measured in the empty, half-full and fully-occupied rooms

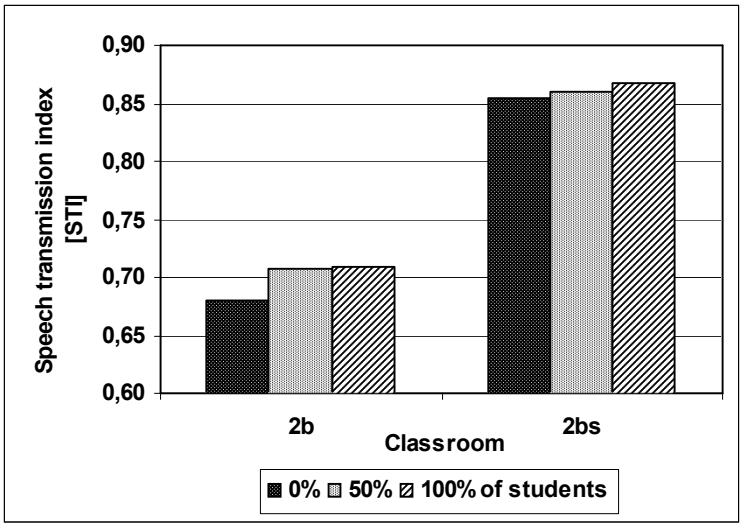


Fig. 5.13 Speech Transmission Index STI in the classroom at the Baumberge Schule before (2b) and after (2bs) the refurbishment, measured in the empty, half-full and fully-occupied room

Even an initial glance at the Speech Transmission Index STI gives a similar picture to that of the reverberation time investigation. With Speech Transmission Index values of sometimes far more than 0.75, all the top floor classrooms (2d, 3d, 4c and 4d) at the Grundschule Stichnathstraße reveal considerably better values even when empty than their counterparts on the ground floor (1a, 1b, 2c and 3c) (Fig. 5.12). As in the case of the reverberation time it is also best to cut off at classroom 3c on the ground floor when determining the STI. When full, it is the only one to obtain the limit STI value > 0.75 ("Very good").

Speech intelligibility was also improved by the refurbishment of the Baumberge Schule The strong reduction of the reverberation time, while it somewhat diminished

the stereoscopic sound, nevertheless lent an almost studio-quality speech intelligibility with a STI of over 0.85 at every level of occupancy! (Fig. 5.13)

Basic parallels between the RT and STI-measurements are not surprising, particularly based on the measurement process, which relies particularly on the analysis of room impulse response when determining the STI (see section 4.1.1). As the data basis here comprises very comparable rooms with similar volumes, similar cubic dimensions, furnishing, occupancy and use, it would appear technically legitimate to compare the two values directly. In fact a regression analysis of the speech intelligibility in direct dependence on the reverberation time in the case of an underlying data basis for all rooms in respectively all levels of occupancy (empty, half-full and full) with a regression line STI = 0.949–0.361*RT and a r = 0.977 demonstrates the mutual dependency unexpectedly clearly (Fig. 5.14). In this context it is worth mentioning a current investigation by MOMMERTZ (2001) in acoustic simulations of classrooms, which calculated a similarly linear relationship between EDT and STI. One may therefore conclude, at least for the normal classrooms investigated here of a normal size and shape, that the average reverberation time of 0.5 s also marks the borderline between "very good" (STI > 0.75) and "good" (STI < 0.75) speech intelligibility.

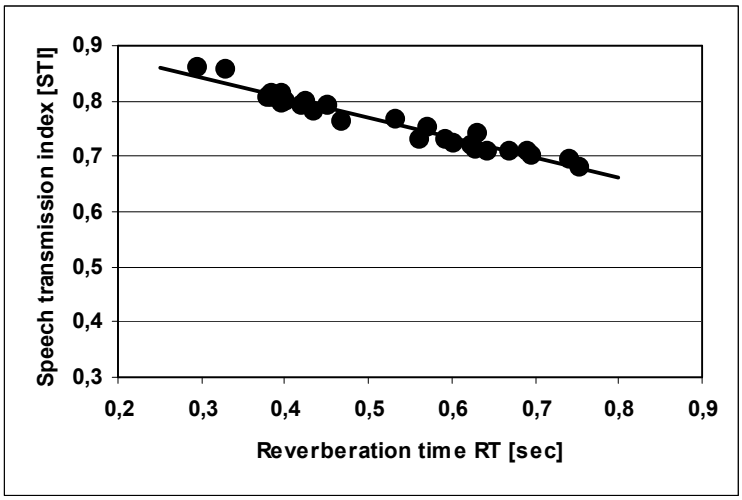


Fig. 5.14 Speech intelligibility STI in relation to the reverberation time RT for all occupancy states in all classrooms

The clear relationship can be sensibly shown in further analysis – at least in the present data record – limited by only one room acoustic filter parameter, because the two values can be related or converted without further processing.

5.1.2 Filter "Pedagogical features" – Internal analysis of the filter parameters T-type and TgS - SgS

The starting point of this chapter is the question of the reality of teaching in our classrooms. How is teaching carried out? Who does the talking in lessons? For how long? And to whom? The analysis of the data collected by the observers enables this question to be answered at least for those schools involved in the investigation. For both examples we are able to draw a rare, objectively quantified picture of the pedagogical events in the classroom. Whether this picture is representative overall for other schools remains open. Nevertheless, the separate observations of the time breakdown of the teaching methods and the shares of speech during the lessons in both schools, represented at the Baumberge Schule, by Class 2b and/or 2bs (▓) and at the Grundschule Stichnathstraße (▒) show some clear differences in the teaching methods – perhaps an indication that the results that follow may be justifiably transferee to other schools with similar work cultures. The school-related data analysis is followed by a focused analysis of individual classes or lessons.

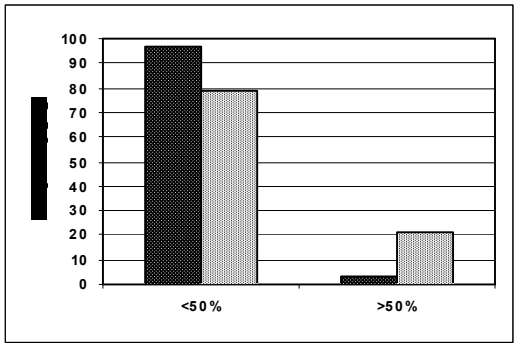


Fig. 5.15 Frequency of time slices with T-type **Individual work**. In comparison: overall result Baumberge Schule, Class 2b/2bs (▓), and Grundschule Stichnath-straße (▒).

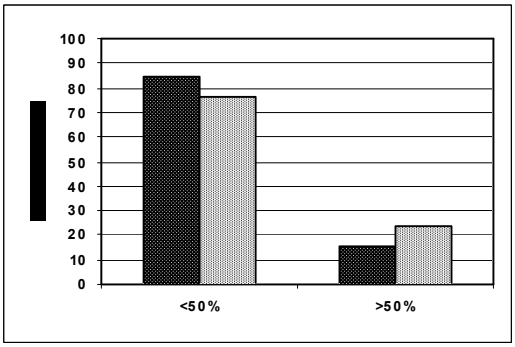


Fig. 5.16 Frequency of time slices with T-type **Working in pairs**. In comparison: overall result Baumberge Schule, Class 2b/2bs (▓), and Grundschule Stichnathstraße (▒).

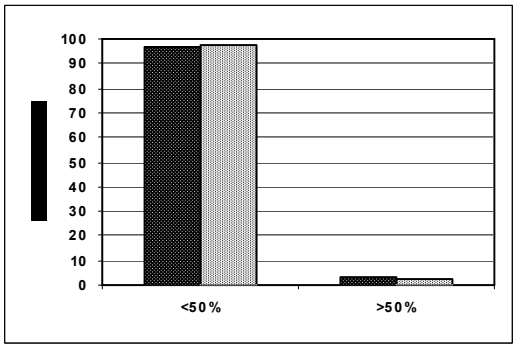


Fig. 5.17 Frequency of time slices with T-type **Working in groups**. In compa-rison: overall result Baumberge Schule, Class 2b/2bs (▓), and Grundschule

Stichnathstraße (▒).

In a first step the individual observation categories relating to the teaching methods are investigated with regard to the timed frequency of their occurrences in the lessons (Fig. 5.15-5.17). In this step, the frequencies of the individual time slices in which the investigated teaching methods (T-type) were over-proportionally represented are determined. The process involves differentiating between phases with shares < 50 % and/or > 50 % of each category (see 4.2.1.2). The left-hand bars ("< 50 %") represent all time slices, in which the totals of all other T-types were greater than that investigated. They are therefore naturally quite large and are not reliable for the purposes of this task.

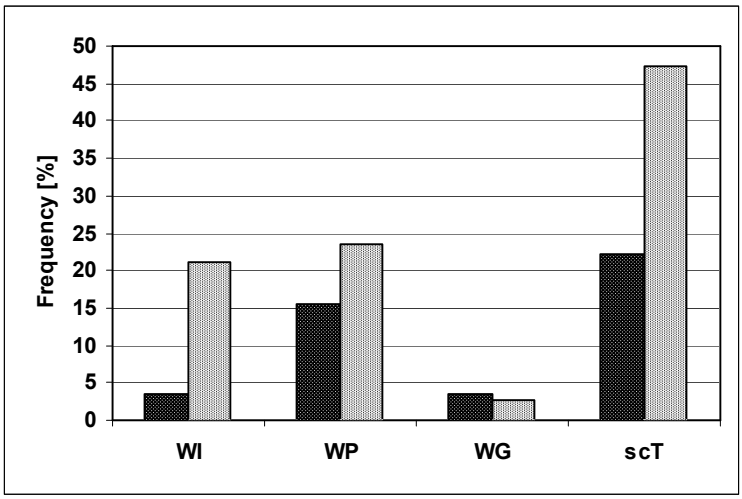


Fig. 5.18 Review of the frequency of time slices with T-type WI, WP, WG and **scT**. In comparison: overall results Baumberge Schule, Class 2b/2bs (▓), and Grundschule Stichnathstraße (▒).

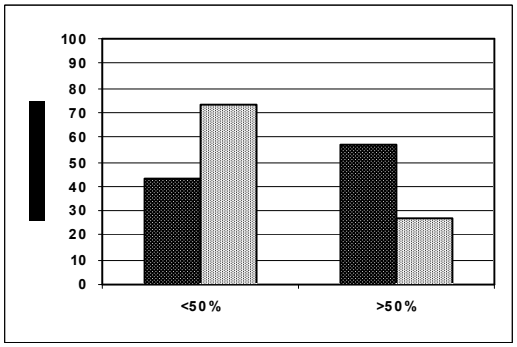


Fig. 5.19 Frequency of time slices with T-type **Direct teaching**. In comparison: Overall result Baumberge Schule, Class 2b/2bs (▓), and Grundschule Stichnathstraße (▒).

The combining of the three categories of individual, partner and group work into the overall category "scT" provides a reliable forecast of the actual temporal orders of magnitude of pupil- centred teaching phases in the two schools (Fig. 5.18). In this case the value for the category scT does not correspond directly to the total of the individual categories but is recalculated each time from the data obtained from each short time interval. The scT category thereby generates a more realistic overall impression over the actual relationship between student-centred and direct working phases. This phenomenon was indicated in section 4.2.1.2. Now the differences between the schools mentioned at the outset become clearly visible: The Grundschule Stichnathstraße total contains some twice as many time slices of student-centred working methods as in the Baumberge Schule. This finds its parallel in the category of "direct teaching" (dT) (Fig. 5.19). The proportion of time spent on organisational and/or other teaching phases is however similar in both schools. (Fig. 5.20 and 5.21)

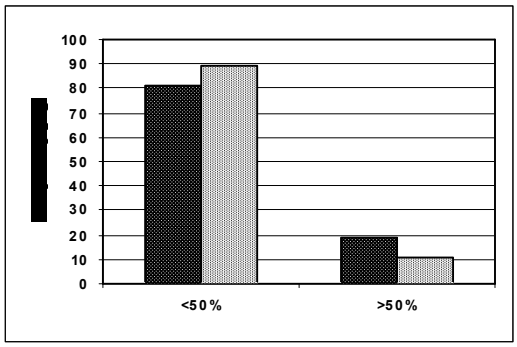


Fig. 5.20 Frequency of time slices with T-type **Organisation**. In comparison: Overall result Baumberge Schule, Class 2b/2bs (▓), and Grundschule Stichnathstraße (▒).

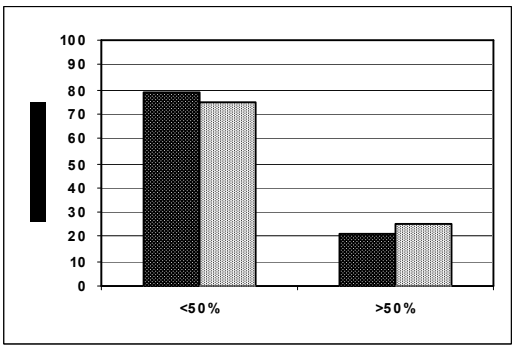


Fig. 5.21 Frequency of time slices with T-type **Other**. In comparison: Overall result Baumberge Schule, Class 2b/2bs (▓), and Grundschule Stichnathstraße (▒).

A direct comparison of the two main categories dT and scT makes clear that the teaching in the class investigated at the Baumberge Schule is different in approach to that in the Grundschule Stichnathstraße; it is more teacher-centred and less characterised by student-centred teaching phases (Fig. 5.22).

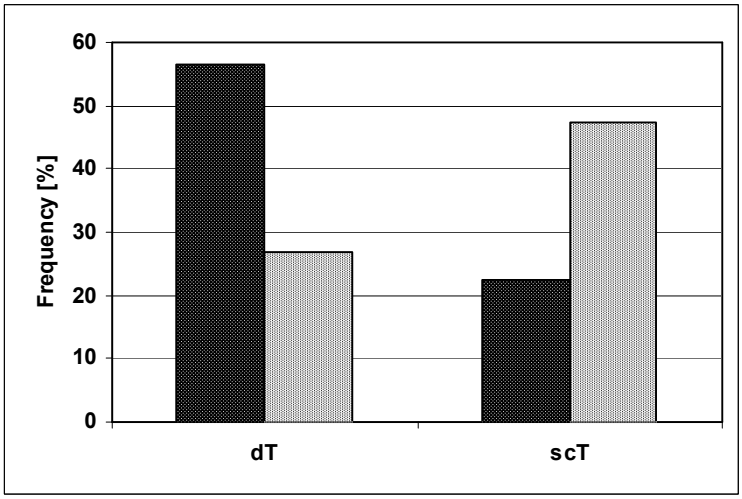


Fig. 5.22 Methods of working in the school comparison. Frequency of time slices with > 50 % dT and/or scT in the Baumberge Schule, Class 2b/2bs (▓), and Grundschule Stichnathstraße (▒).

In the case of the overall presentation based on a "teaching grid", which incorporates the organisation and other working phases, the difference is equally clear. While the grid for the Baumberge Schule shows a distinctly upwards trend (dT), the diagram for the Grundschule Stichnathstraße equally clearly shows a right-hand bias (scT) (Fig. 5.23 and Table 5.1).

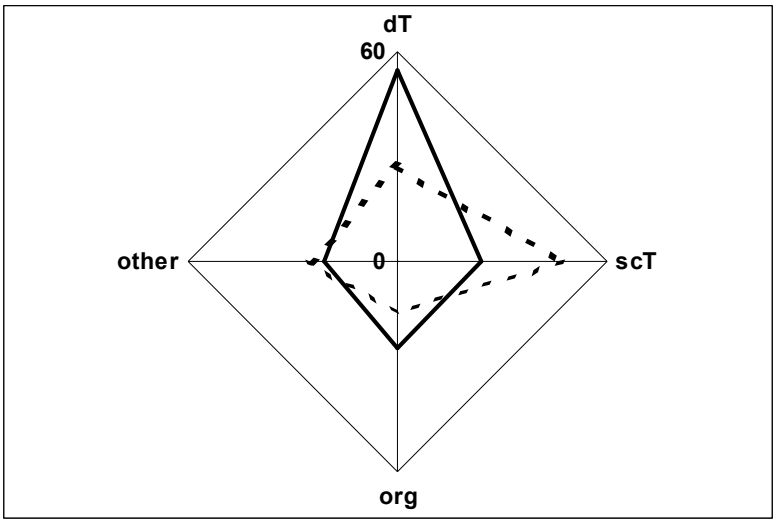


Fig. 5.23 Teaching grid for the frequency of the teaching methods of dT, scT, org and other. School comparison between the Baumberge Schule; Class 2b/2bs (—), and Grundschule Stichnathstraße (- - -). Details in %

Table 5.1 Individual data for Fig. 5.23
Note: the total of the individual categories exceeds 100 % because the "Organisation" characteristic may be recorded simultaneously with the other categories.

	Baumberge	**Stichnathstraße**
dT	54.79 %	27.04 %
scT	23.91 %	47.65 %
Org	24.53 %	14.49 %
Other	20.91 %	24.95 %

This does not mean in any way that the pupils in the Baumberge Schule were less involved in the teaching events than those in the Grundschule Stichnathstr! Even the overall view of the above categorisation with the actual shares of speech in the teaching produces a uniform picture. If one compares these (see teaching grid; Fig. 5.24) one sees that in Class 2b/2bs at the Baumberge Schule, despite high shares of

direct teaching, the time slices were equally dominated by student-generated speech (sgS).
This is also shown in the direct comparison with a comparable class from the Grundschule Stichnathstraße (in this case Class 3c). The two classrooms, with a similar room size and number of pupils, differ primarily in their seating arrangements. The pupils in the Baumberge Schule are arranged in a horseshoe shape around the board area while the tables in Class 3c at Stichnathstraße are grouped together. (Fig. 5.25 and 5.26)

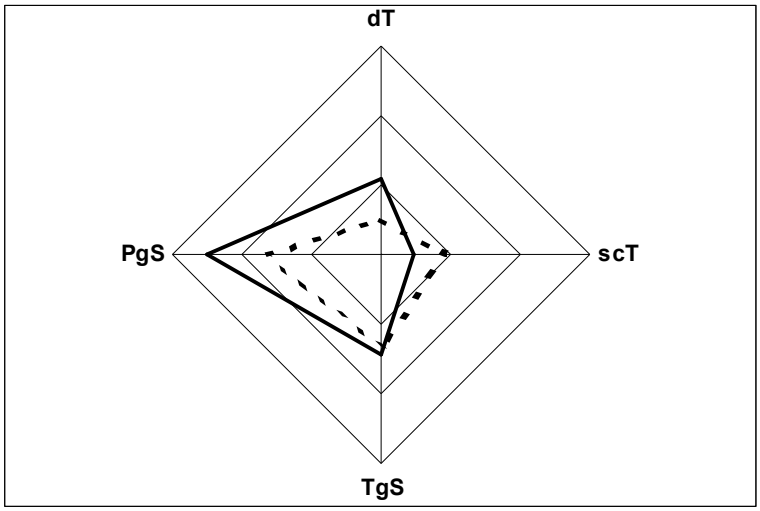


Fig. 5.24 Teaching grid for the frequency of the teaching methods dT and scT and SgS and TgS shares of speech. Comparison between the Baumberge Schule; Class 2b/2bs (—), and Grundschule Stichnathstraße; (- -). Details in %; On a scale of 0 to 150.

Fig. 5.25 Classroom of Class 3c at the Grundschule Stichnathstraße

Fig. 5.26 Classroom of Class 2b at the Baumberge Schule

As expected, these seating arrangements are reflected in the teaching methods. The teacher of Class 2b (Baumberge Schule) tends to use considerably more direct teaching than her colleague in Class 3c (Grundschule Stichnathstraße). The pupils in both classes are nevertheless intensively involved in the teaching events. It would

therefore appear that the ratio of pupil and teacher-generated speech is not fundamentally determined in either class by the teaching method (Fig. 5.27).

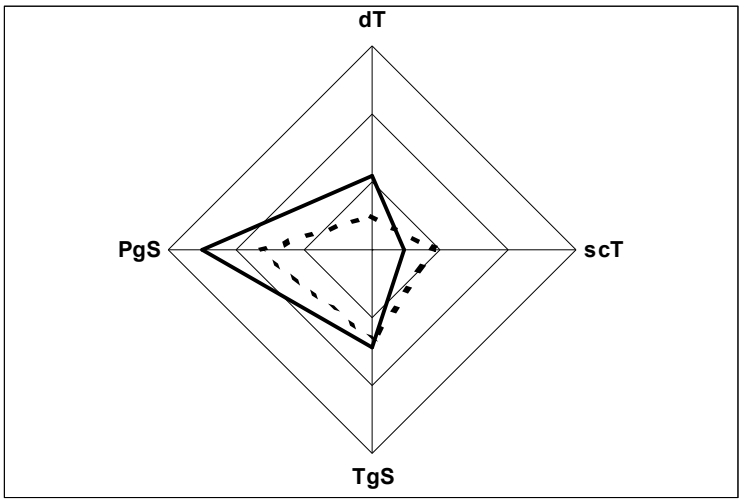


Fig. 5.27 Teaching grid for the frequency of the teaching methods dT and scT and shares of SgS and TgS. Comparison of classes between class 2b; Baumberge Schule (—), and class 3c; Grundschule Stichnathstraße (- -). Details in %; On a scale of 0 to 150%.

This is sufficient reason to take a much closer look at the relationship between teaching methods and shares of speech:

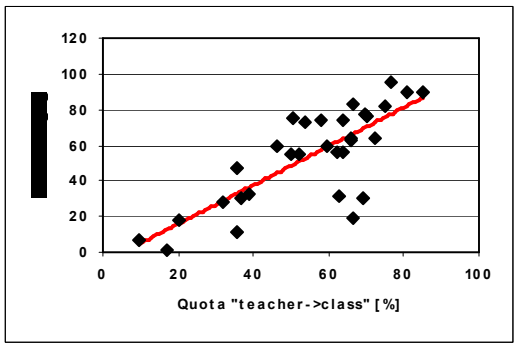


Fig. 5.28 Percentage of time of teacher-generated speech to the whole class in relation to the teaching method; in this case dT. Data basis: Baumberge Schule overall

*Y = A + B*X*

N	*A*	*B*	*R*	*R²*
31	*-5.93*	*1.09*	*0.78*	*0.61*

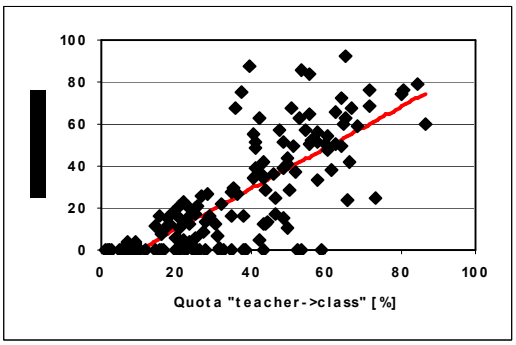


Fig. 5.29 Percentage of time of teacher-generated speech to the whole class in relation to the teaching method; in this case dT. Data basis: Grundschule Stichnathstraße overall

*Y = A + B*X*

N	*A*	*B*	*R*	*R²*
144	*-9.71*	*0.97*	*0.76*	*0.57*

In fact while an analysis of whole lessons based on whole lessons (45 min. time slices), as one might expect, shows that the percentage of teacher-generated speech to the whole class increases with an increase in direct teaching methods, (Fig. 5.28

and 5.29) and/or teacher-generated speech to the whole class decreases with the increase in student-centred teaching methods (Fig. 5.30 and 5.31), regression rates are only moderate. Overall the relationship between the share of teacher speech and the teaching methods is not as great as initially expected. For example the teacher also speaks more frequently to the whole class during student-centred teaching phases (individual, partner and group work) than to individual pupils or working groups.

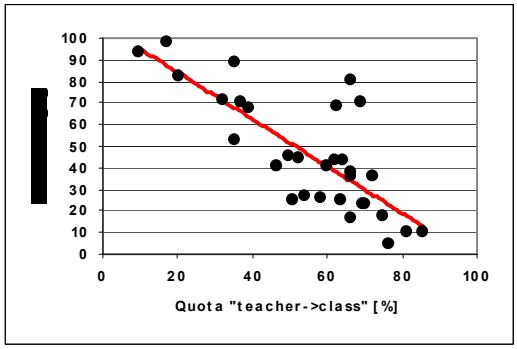


Fig. 5.30 Percentage of time of teacher-generated speech to the whole class in relation to the teaching method; in this case scT. Data basis: Baumberge Schule overall

*Y = A + B*X*

N	*A*	*B*	*R*	*R²*
31	*105.93*	*-1.09*	*0.78*	*0.61*

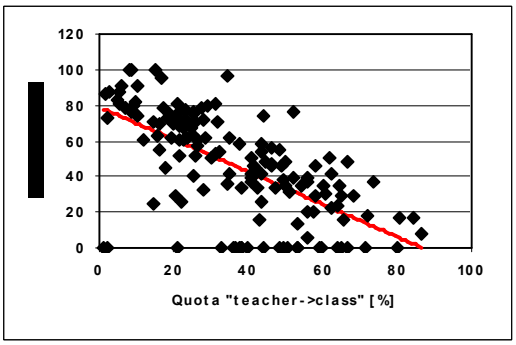


Fig. 5.31 Percentage of time of teacher-generated speech to the whole class in relation to the teaching method; in this case scT. Data basis: Grundschule Stichnathstraße overall

*Y = A + B*X*

N	*A*	*B*	*R*	*R²*
144	*79.03*	*-0.91*	*0.64*	*0.41*

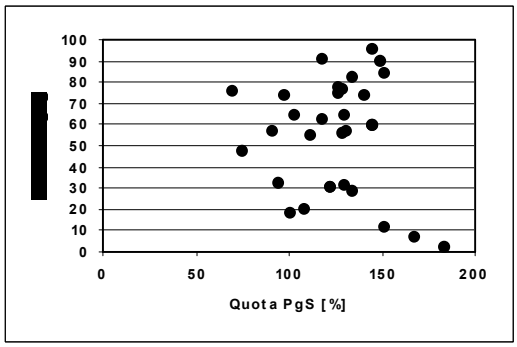


Fig. 5.32 Percentage of time of student-generated speech in relation to the teaching method; in this case dT. Data basis: Baumberge Schule overall

*Y = A + B*X*

N	*A*	*B*	*R*	*R²*
31	*73.26*	*-0.15*	*0.14*	*0.02*

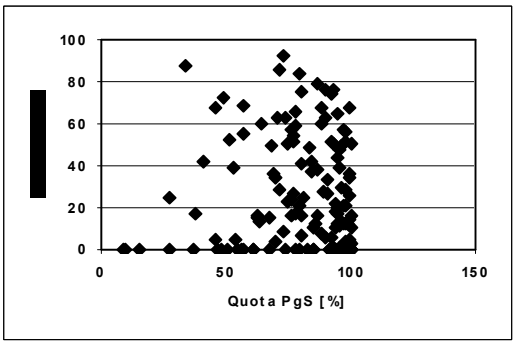


Fig. 5.33 Percentage of time of student-generated speech in relation to the teaching method; in this case dT. Data basis: Grundschule Stichnathstraße overall

*Y = A + B*X*

N	*A*	*B*	*R*	*R²*
144	*28.20*	*-0.03*	*0.03*	*0.00*

Accordingly there is no evidence of a relationship between the shares of time of student-generated speech and the teaching method (Figs. 5.32 and 5.33). Finally there is no relationship between the percentage of time of overall teacher-generated speech and teaching methods (Figs. 5.34 to 5.37). The teacher is always talking; whether involved in direct or student-centred teaching – a significant percentage of the teaching time is dominated by teacher-generated speech! (However, this does not seem to have a detrimental effect on pupils.)
Consequently the events in the classroom cannot be adequately described with conventional stereotypes from a technical acoustic communication perspective. "Direct teaching" also does not mean that the teachers lecture without pause (key phrase "direct teaching discussion"). Equally, student-centred teaching methods do not mean that the teacher stops speaking to the whole class.

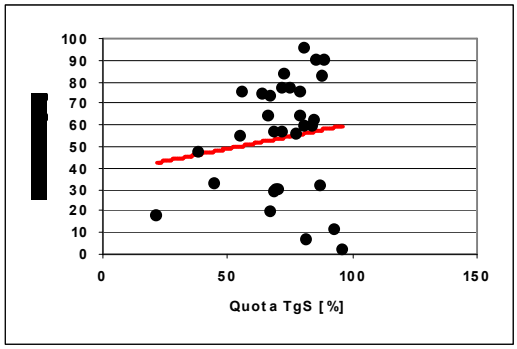


Fig. 5.34 Percentage of time of overall teacher-generated speech in relation to the teaching method; in this case dT. Data basis: Baumberge Schule overall

*Y = A + B*X*

N	*A*	*B*	*R*	*R²*
31	*37.53*	*0.23*	*0.14*	*0.02*

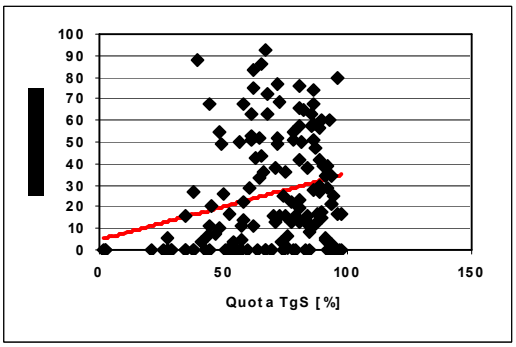


Fig. 5.35 Percentage of time of overall teacher-generated speech in relation to the teaching method; in this case dT. Data basis: Grundschule Stichnathstraße overall

*Y = A + B*X*

N	*A*	*B*	*R*	*R²*
144	*4.75*	*0.31*	*0.25*	*0.06*

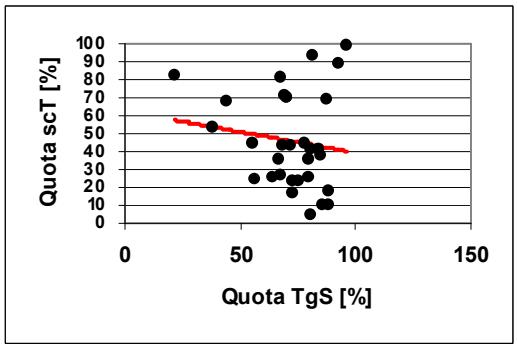


Fig. 5.36 Percentage of time of overall teacher-generated speech in relation to the teaching method; in this case scT. Data basis: Baumberge Schule overall

*Y = A + B*X*

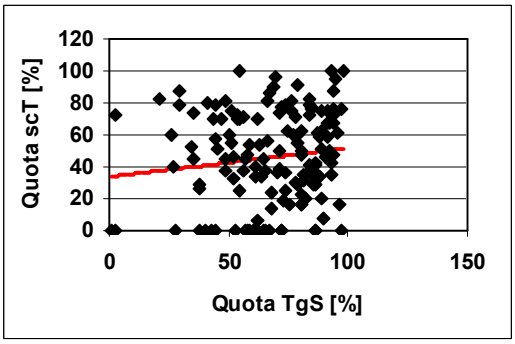


Fig. 5.37 Percentage of time of overall teacher-generated speech in relation to the teaching method; in this case scT. Data basis: Grundschule Stichnathstraße overall

*Y = A + B*X*

N	A	B	R	R^2	N	A	B	R	R^2
31	62.47	-0.23	0.14	0.02	144	33.70	0.18	0.13	0.018

The age and time-dependent breakdown of the teaching method and shares of speech offers a further insight into the so-called "reality of teaching". The analysis of the teaching methods in relation to the year group demonstrates again the different basic concepts of the Baumberge Schule and Stichnathstraße. Figure 5.38 is a direct comparison of all the year 2 classes. Since Class 2b in the Baumberge Schule was monitored twice (before and after the refurbishment) and there are therefore two data records available, it is referred to hereafter as Class 2b and as Class 2bs. The data relates to the same pupils and the same teacher. However, the teaching took place under different basic conditions.

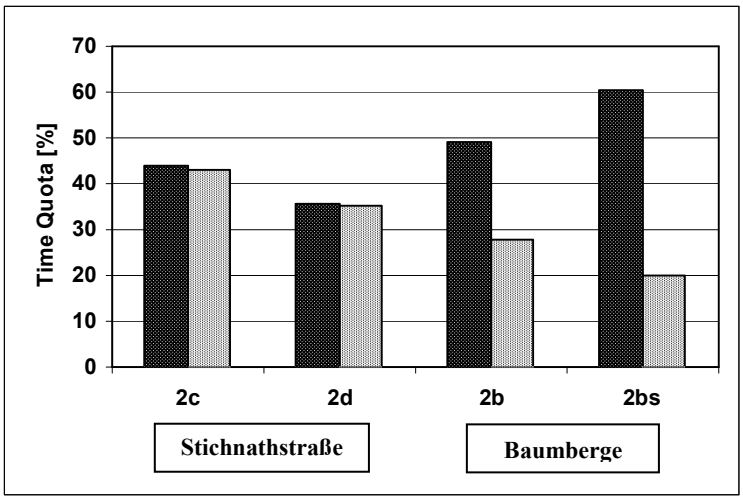


Fig. 5.38 Comparison of the teaching methods dT (▓) and scT (▒) between the year 2 classes

The two year-two classes 2c and 2d for their part are not representative of the whole of the Grundschule Stichnathstraße. The class breakdown reveals clear differences in the working behaviour (Fig. 5.39). This data does not show whether this is age-motivated or relates to the pedagogical preferences of the teacher. It is clear, however, that in the older classes (years three and four) the trend towards predominantly student-centred teaching methods is evident, while teaching methods lower down the school (years one and two) are about evenly divided.

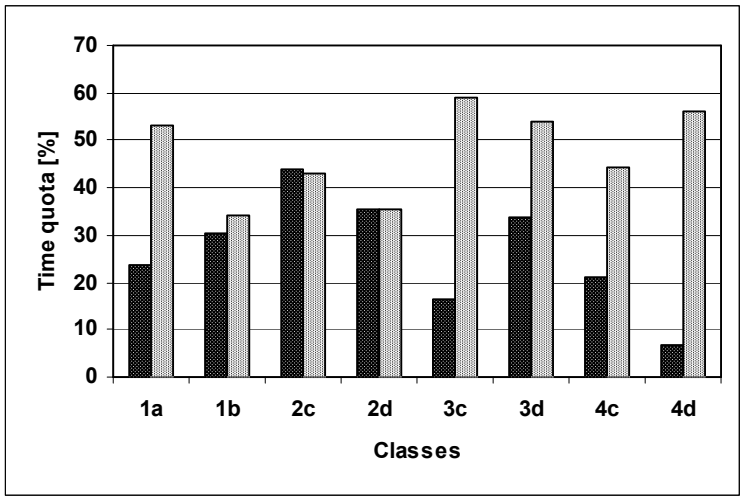


Fig. 5.39 Comparison of teaching methods dT (▓) and scT (▒) between all classes at the Grundschule Stichnathstraße

However an observation of the speech shares shows once again that a dominant and/or equally high percentage of direct teaching does not lead to linguistic inactivity on the part of the pupils in either the Baumberge Schule or in the lower classes of the Grundschule Stichnathstraße. Figures 5.40 and 5.41 show a consistent distribution of shares of speech in nearly all year groups in both schools.

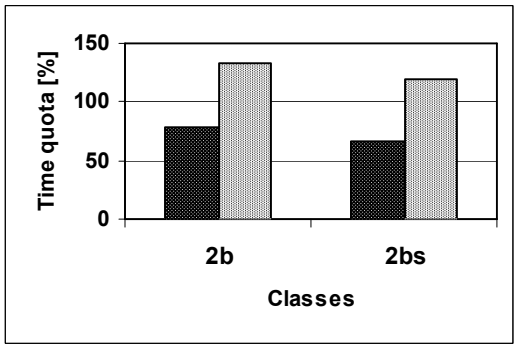


Fig. 5.40 Comparison of shares of speech in teaching sorted according to TgS (▓) and SgS (▒) in the Baumberge Schule

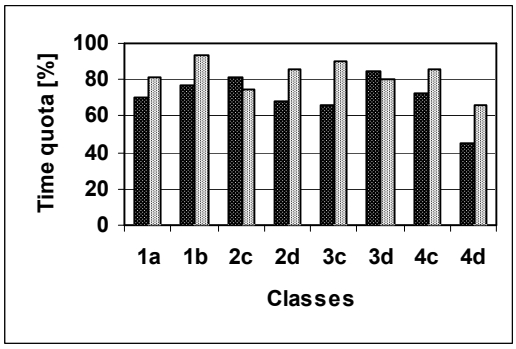


Fig. 5.41 Comparison of shares of speech in teaching sorted according to TgS (▓) and SgS (▒) in the Baumberge Schule

Also worthy of note is a slight trend towards a year-group dependant congruence of shares of speech. Overall, there was less talking in the year four classes of the Stichnathstraße than in the younger year groups. This effect is more than averagely caused by the communicative behaviour in Class 4d and should not therefore be overlooked (Fig. 5.41).

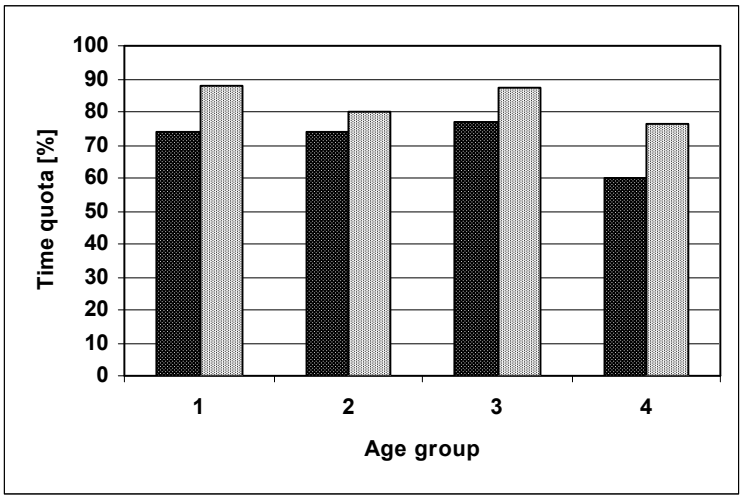


Fig. 5.42 Distribution of teacher-generated speech TgS (▓) and student-generated speech SgS (▒) in the Grundschule Stichnathstraße; sorted according to year group

It becomes even clearer, if one returns from the larger time shares to an analysis of the time slices. It is now evident that the time slices dominated by teacher-generated speech are less frequent in the fourth year group than in years 1 to 3 (Fig. 5.42). This trend towards a reduction of the shares of speech in the year-four group is also evident in the student-generated speech (Fig. 5.42), while not as distinctly as the teacher-generated speech. However the frequency of "silent" time slices, i.e. those moments in which either teacher or pupils are speaking less than 50 % of the time, rises in the year-four classes (Fig. 5.43 and 5.44). This increase can be detected both for the teacher- and the student-generated speech. Whether this is due to the higher concentration abilities of the 10 year-olds, better social behaviour or completely different influential factors (e.g. pedagogical preference of the teacher) is a matter of speculation at this point.

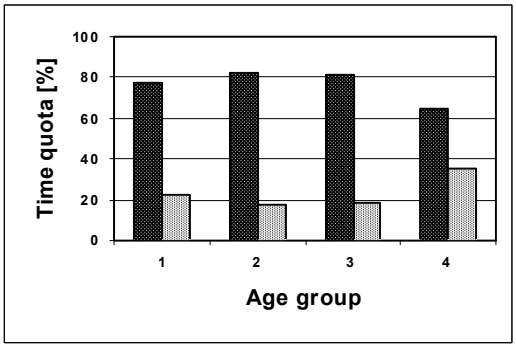


Fig. 5.43 Distribution of shares of speech in teaching
Teacher-generated speech time slices wherein SumTgS > 50 % (▓) and SumTgS < 50 % (▒) in the Grundschule Stichnathstraße; sorted according to year group

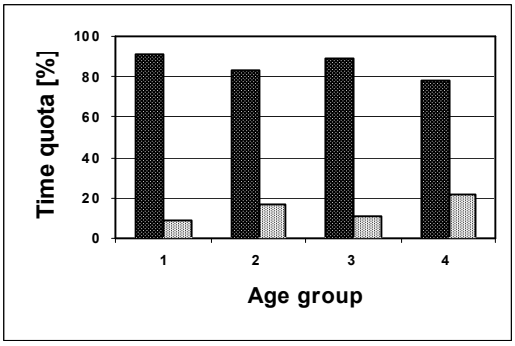


Fig. 5.44 Distribution of shares of speech in teaching
Student-generated speech time slices wherein SumSgS > 50 % (▓) and SumSgS < 50 % (▒) in the Grundschule Stichnathstraße; sorted according to year group

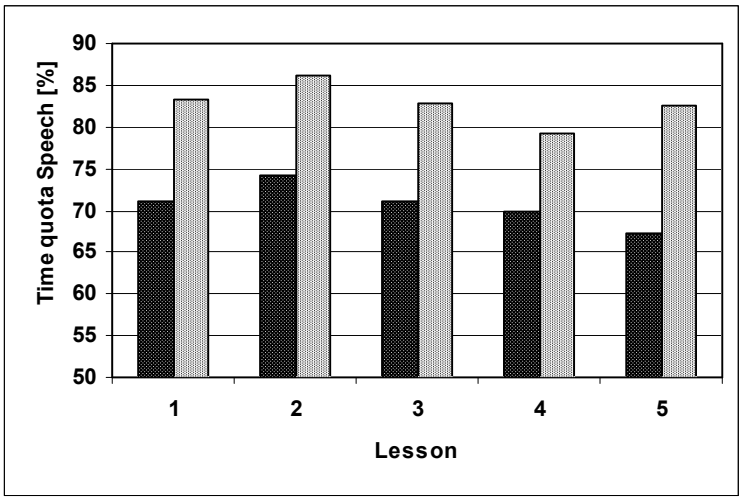


Fig. 5.45 Distribution of teacher-generated speech (▓) and student-generated speech (▒) throughout the course of the day at the Grundschule Stichnathstraße; sorted according to lessons (all classes)

Another matter for speculation is the realisation that the shares of speech – particularly the shares of speech of teachers – at Stichnathstraße reduce considerably over the school morning. Figure 5.45 provides the average values of the speech shares of all the teachers involved in investigation at Stichnathstraße. Unlike their pupils they decrease steadily over the morning. A fatigue phenomenon? If yes, the question remains as to why this phenomenon is absent for the teacher at the Baumberge Schule. By midweek her shares of speech remain largely constant over the morning and even increase slightly in the last two lessons (Fig. 5.46)

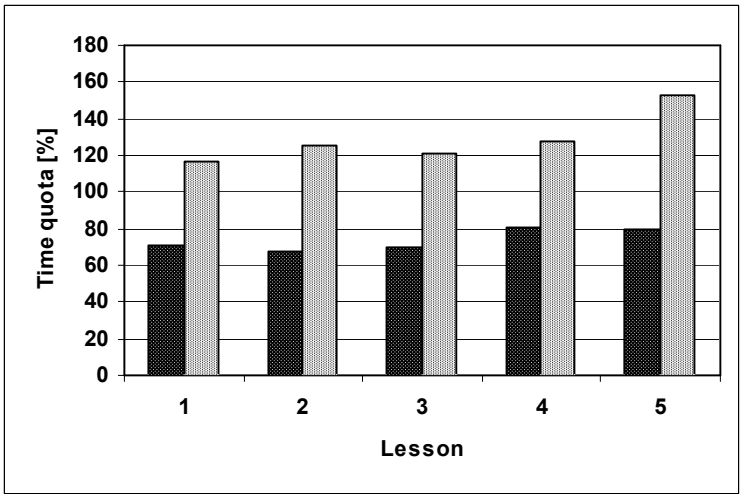


Fig. 5.46 Distribution of teacher-generated speech (▓) and student-generated speech (▒) throughout the course of the day at the Baumberge Schule; sorted according to lessons

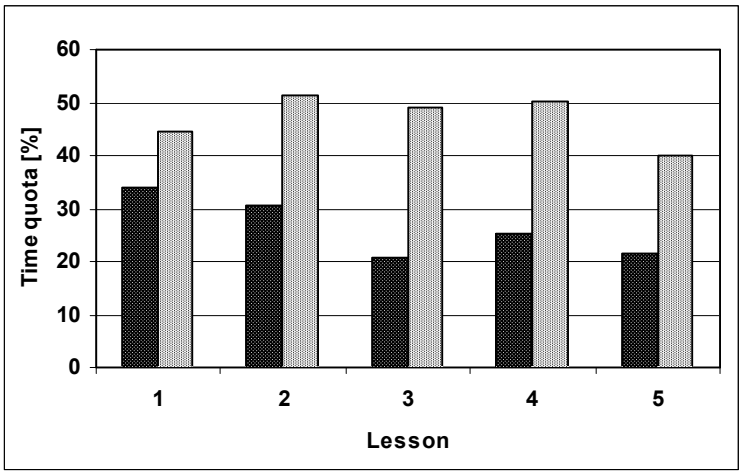


Fig. 5.47 Distribution of the teaching methods dT (▓) and scT (▒) in the Grundschule Stichnathstraße throughout the course of the day; sorted according to lessons

The present data provides no answer to this observation. One possible reason is the different levels of fatigue of the teaching staff (if this is actually evidence of fatigue) and another is the very different social milieu of the pupils while yet another may even be the preferred teaching method. Do the open, student-centred teaching methods in the Stichnathstraße contribute to this fatigue, while the more easily controlled direct teaching methods of their colleague in the Baumberge Schule prevent this and thereby conserve resources which can be used later during increased speech activity and a more open teaching method?

It is worth noting in fact that the student-centred teaching methods that so clearly characterise the teaching methods at Stichnathstraße, are used less in the last lesson (Fig. 5.47), while a completely different situation is revealed at the Baumberge Schule. In the last two lessons the teacher increasingly abandons the, until then dominant, direct teaching methods and surprisingly turns to student-centred methods (Fig. 5.48).

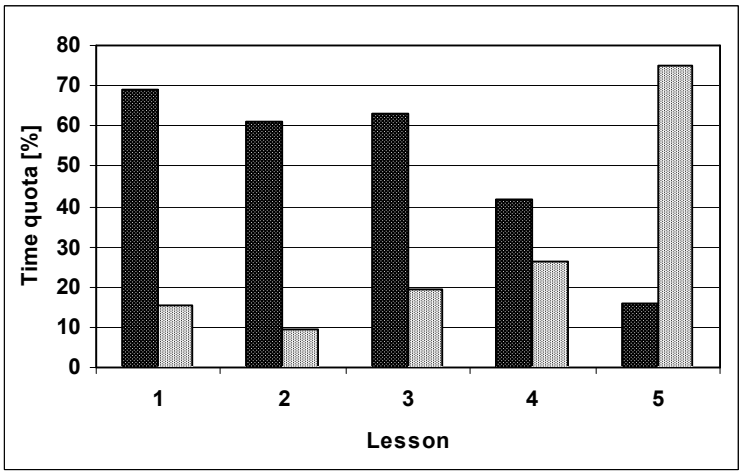


Fig. 5.48 Distribution of dT (▓) and scT (▒) teaching methods in the Baumberge-Schule throughout the course of the day; sorted according to lessons

Ultimately, most of the relationships between these aspects cannot be satisfactorily explained within the context of this investigation. However the following analysis of the noise level and the heart rate may provide more pieces of the jigsaw.

5.1.3 Interdependence of the filters and/or filter parameters

Before the actual analysis of the reaction values of noise level and heart rate it is necessary to clarify whether and to what extent their respective filter parameters depend on one another. One might ultimately assume for example that the room's acoustic environment has an influence on the decision of the teacher to favour this or that teaching method. If one can confirm such a relationship, this would have consequences for the subsequent proceedings since the pedagogical teaching methods would themselves represent reaction values with regard to the room acoustics. The same applies if it can be demonstrated that a certain room acoustic environment resulted in a particular speech behaviour, especially either good or bad speech intelligibility (for which assumption there is equal justification).
The possible impacts of a changed reverberation time on the teaching events can be most reliably checked at the Baumberge Schule, which offers easily monitored consistent parameters. The same teacher teaches the same class in the same classroom with the same timetable. Since the only difference is the changed reverberation time, one can consider the comparison conditions to be almost laboratory standard. A first glance at the teaching method grid provides a further confirmation of similarity for both weeks. The teacher employed the same teaching methods both weeks. Those methods in turn involved a similar mix of speech shares (Fig. 5.49).

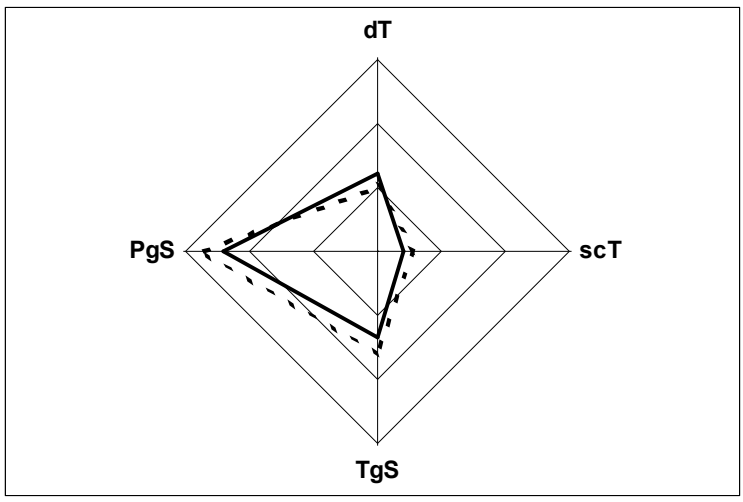


Fig. 5.49 Methods of working and shares of speech in the Baumberge Schule before (- -) and after (——) the refurbishment. Data basis: all lessons

A glance at the frequency distribution confirms this pattern. While the ratio of time units in which direct teaching prevailed and those in which student-centred teaching dominated has shifted slightly (Fig. 5.50), these changes are certainly not within the basic range. The frequency distribution of shares of speech however verifies the direct comparability of both teaching weeks (Fig. 5.51).

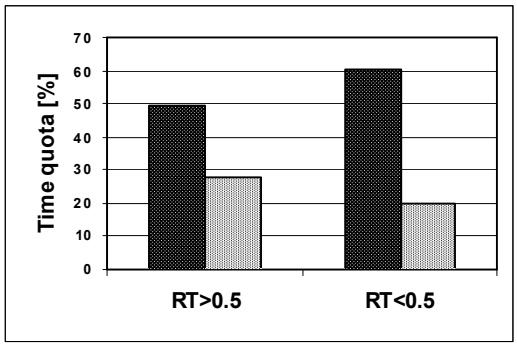


Fig. 5.50 Teaching methods dT (▓) and scT (▒) in the Baumberge Schule before and after the refurbishment; Data basis: all lessons

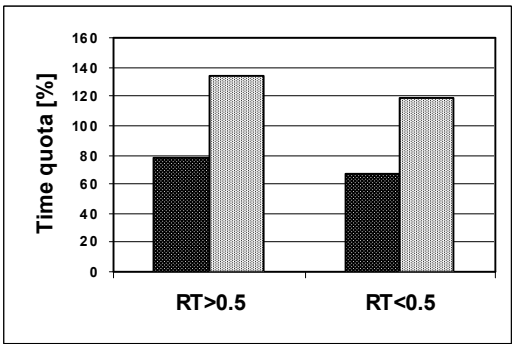


Fig. 5.51 Shares of speech, TgS (▓) and SgS (▒) in the Baumberge Schule before and after the refurbishment; Data basis: all lessons

A similar picture emerges in a comparison of rooms in the Grundschule Stichnathstraße with a reverberation time RT < 0.5 s with those with a RT > 0.5 s. One must not forget that the uncertainty factor in this school is certainly greater than in the Baumberge Schule (different teachers, different classes, different year groups, different classrooms). If one ventures a direct comparison bearing this in mind, one sees that here too the pedagogical school culture is not dependent on the acoustic quality of the classroom (teaching method grid; Fig. 5.52). This is doubly significant. Firstly it confirms that the two filter values are not dependent on one another and secondly it provides a central condition for the subsequent analysis of the reaction values, i.e. indicates as far as possible constant filter characteristics.
A comparison within the year groups also shows clearly that the choice of the teaching method depends more on the pedagogical preferences of the teacher than on the room acoustics. This can be seen for example in the second and third classes. One class from each year group is taught in a classroom with a RT < 0.5 s, the other in a classroom with a RT > 0.5 s. The teaching method grids confirm that here again there is no obvious relationship between the teaching method and the room acoustics (Fig. 5.53 and 5.54).

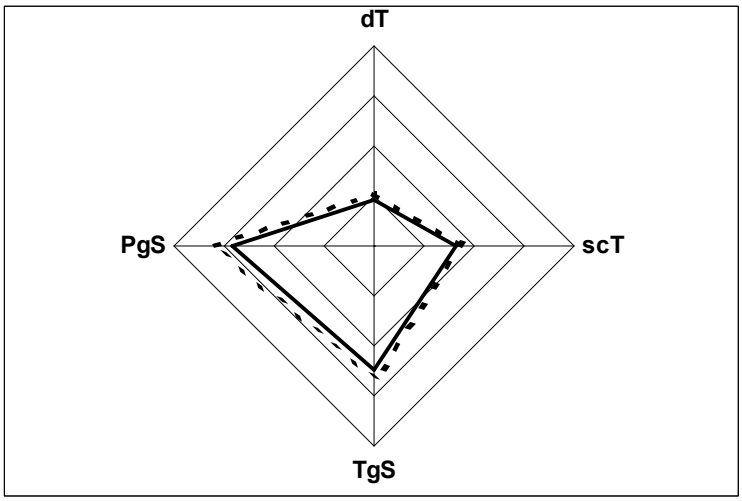


Fig. 5.52 Methods of working and shares of speech in the Grundschule Stichnathstraße with RT > 0.5s (- -) and RT < 0.5s (——)

Data basis: all lessons

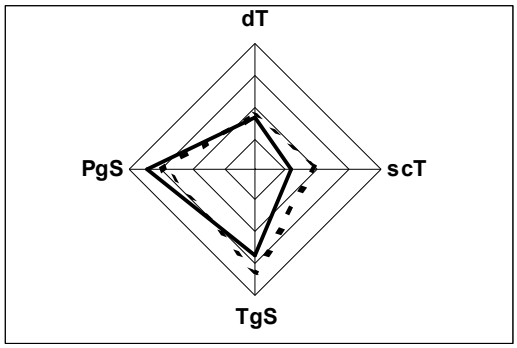


Fig. 5.53 Methods of working and shares of speech RT > 0.5s (**- -**) and RT < 0.5s (——); Stichnathstraße; Comparison of classes 2c and 2d

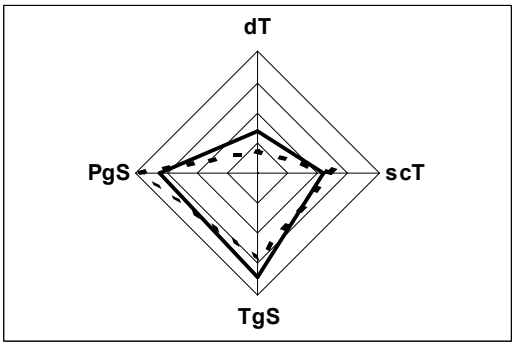


Fig. 5.54 Methods of working and shares of speech RT > 0.5s (**- -**) and RT < 0.5s (——); Stichnathstraße; Comparison of classes 3c and 3d

A glance at the frequency distribution of the teaching methods and shares of speech in the Grundschule Stichnathstraße also confirms this impression. The same teaching methods are used in the classrooms with reverberation times of RT > 0.5 s as their counterparts with reverberation times of RT < 0.5 s. Despite different levels of speech intelligibility the amount of speech is at least qualitatively the same in both rooms (Fig. 5.55 and 5.56).

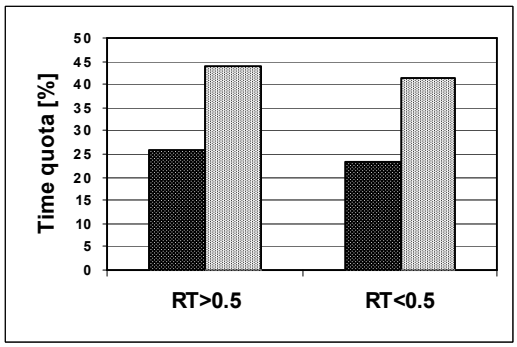


Fig. 5.55 Direct and scT teaching me-thods in the Grundschule Stichnathstraße wherein RT > 0.5s and RT < 0.5s; Data basis: all lessons, all year groups

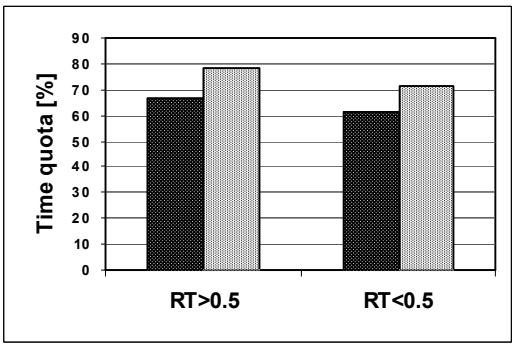


Fig. 5.56 Shares of speech, TgS (▒) and SgS in the Grundschule Stichnathstraße wherein RT > 0.5s and RT < 0.5s; Data basis: all lessons, all year groups

Therefore the two filter values of room acoustics and pedagogical features can be assumed as being independent. The methodological pairing of pedagogical characteristics with the parameters of teaching method and shares of speech prove to be a sound filter value.

5.2 Analysis of reaction values

5.2.1 Analysis of the noise level

5.2.1.1 Analysis of the noise level in relation to the room acoustics

The most important source of information about the question of the effects of the room acoustic conditions on the noise level in teaching methods is once again the Baumberge Schule because the observed teaching weeks differ only in this one respect and also because it offers almost laboratory-standard monitoring conditions. The monitored lesson units took place with the same teacher, the same class and the same timetable in the same classroom. Only the new acoustic ceiling changed the working conditions (see 5.1.1). This change however had an unexpectedly distinct impact on the teaching events. Both the working SPL, expressed as $L_{Aeq,5min}$, as well as the basic SPL, expressed as $L_{A95,5min}$, were clearly affected by the room acoustics. The Figure 5.57 shows the shift in the average frequency of the working SPL and/or basic SPL in Figure 5.58 measured during the lessons.

In this case the difference in the basic SPL of the class is even clearer than in the working SPL. As the latter is also considerably influenced by the teaching methods (see 5.2.1.2), the basic SPL is a valuable indicator for the actual learning environment, i.e. the basic requirement for the events in the classroom.
After the refurbishment the maximum distribution over two classes was less than previously, corresponding to 6 dB(A), with an otherwise similar distribution. The level reductions can be detected not only in the average values but also within individual examples.

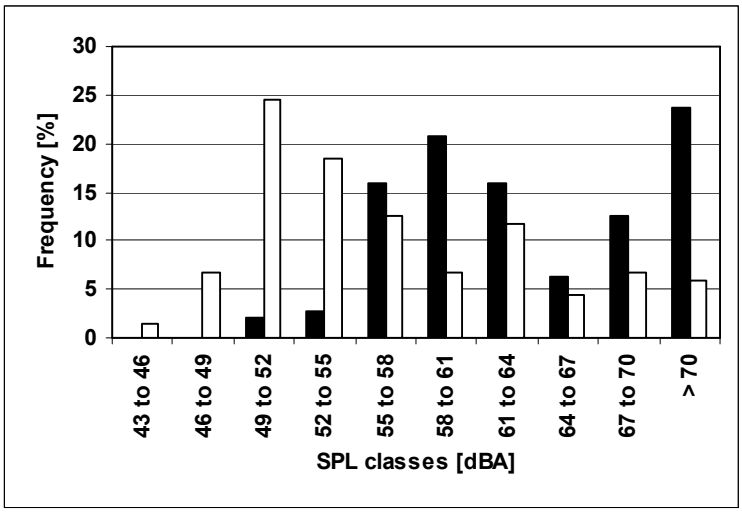


Fig. 5.57 Frequency distribution of the working SPL $L_{Aeq,5min}$ before (■) and after (□) the refurbishment (Baumberge Schule; all lessons)

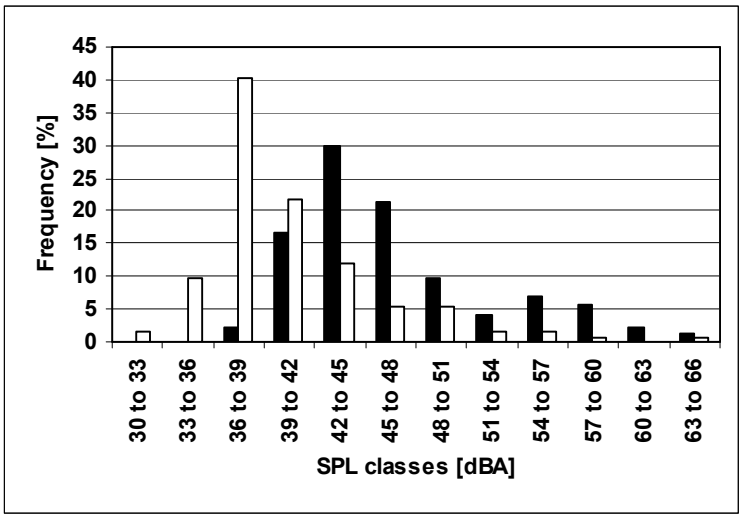


Fig. 5.58 Frequency distribution of the basic SPL $L_{A95.5min}$ before (■) and after (□) the refurbishment (Baumberge Schule; all lessons)

A comparison of directly corresponding teaching methods situations as can be found at the Baumberge Schule due to the very similar parameters clearly shows the impact of acoustic refurbishment of the room. Figures 5.59 and 5.60 reflect the working and basic SPLs of two corresponding lessons under identical conditions before and after the refurbishment. The line marks the actual lesson, the gaps represent breaks.

The comparability of the procedures and therefore the reproducibility of the lesson events are clearly discernible. Also very obvious are the respective rises in levels during break times. The unusually stark increase in the basic SPL after the second lesson after refurbishment gives room for speculation. Is it the reaction of pupils to the previous long period of concentration with a very low basic SPL? It would be great to be able to say that the activities are distributed over the time periods provided for them: concentrated work during the lessons and charging about and shouting during the breaks.

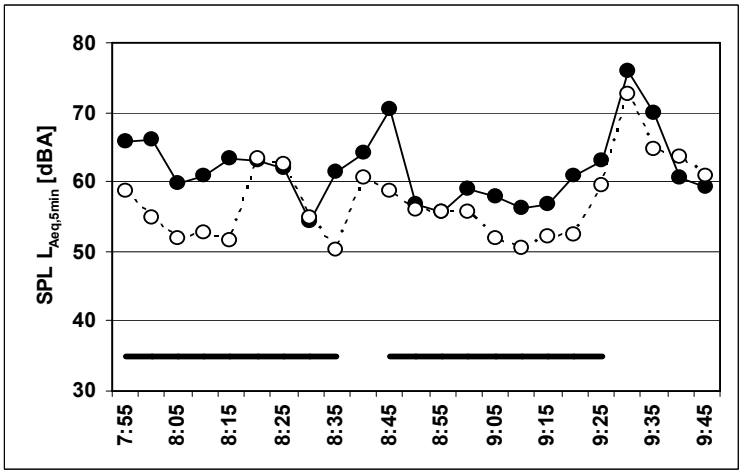


Fig. 5.59 Working SPL $L_{Aeq,5min}$ before (●) and after (○) the refurbishment for two identical lessons (Thursday periods 1 and 2)

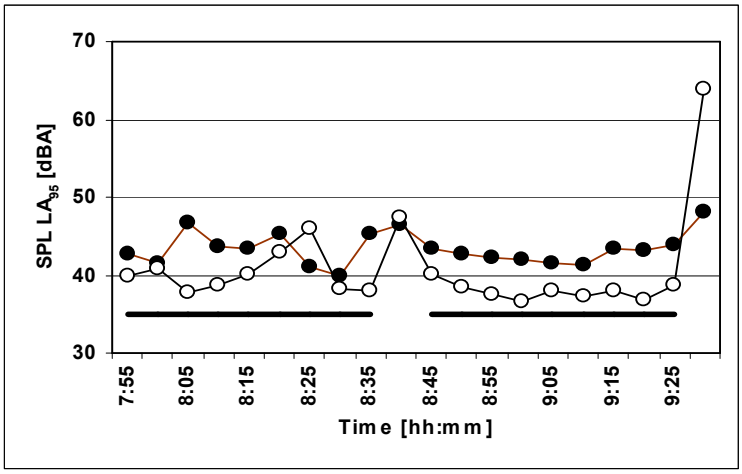


Fig. 5.60 Basic SPL $L_{A95.5min}$ before (●) and after (○) the refurbishment for two identical lessons (Thursday lessons 1 and 2)

Fig. 5.61 Change in the basic SPL $L_{A95.5min}$ due to refurbishment for identical situations (see above)

It seems fair to say that the two lessons before and after the refurbishment, respectively periods one and two on Thursday morning, differ considerably in their basic SPL in a direct comparison (Fig. 5.61) and are therefore typical of the general trend of the changes caused by the refurbishment.

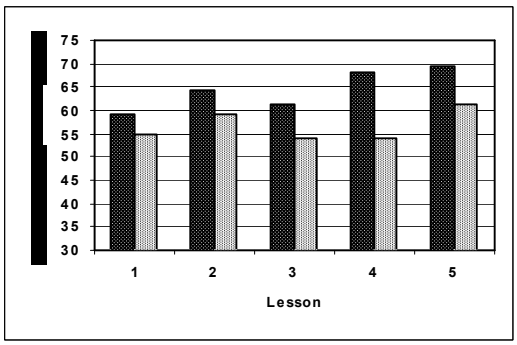


Fig. 5.62 Average working SPL $L_{Aeq,5min}$ before (■) and after (□) the

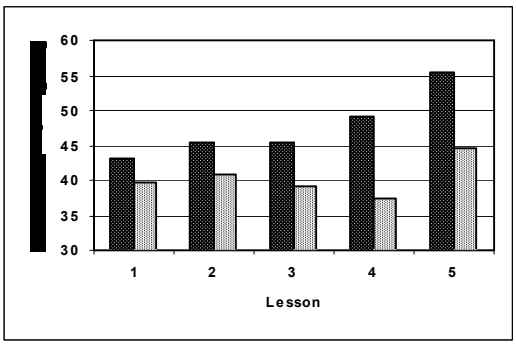


Fig. 5.63 Average basic SPL $L_{A95,5min}$ before (▓) and according to (▒) the

refurbish-ment (Baumberge Schule; all lessons.; sorted according to lessons on the day)

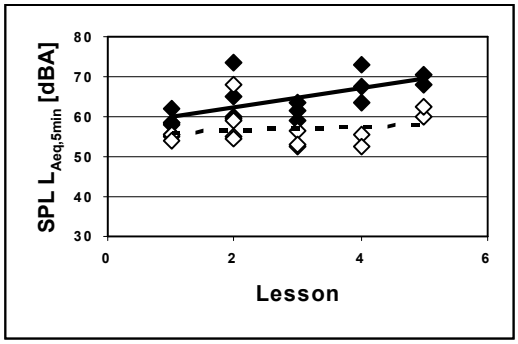


Fig. 5.64 Individual values and regression for Fig. 5.62

*Y = A + B*X*

	N	*A*	*B*	*R*	*R²*
before	*16*	*59,60*	*2,53*	*0,68*	*0,47a*
after	*15*	*59,01*	*0,84*	*0,22*	*0,048*

refurbishment (Baumberge-Schule; all lessons.; sorted according to lessons on the day)

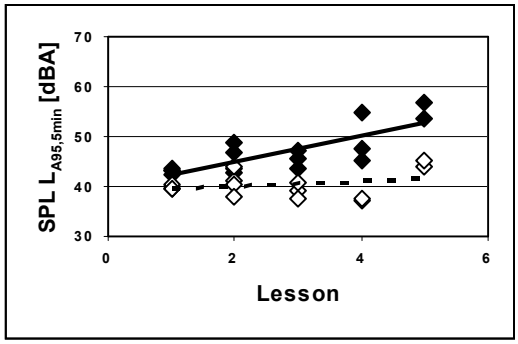


Fig. 5.65 Individual values and regression for Fig. 5.63

*Y = A + B*X*

	N	*A*	*B*	*R*	*R²*
before	*16*	*48,90*	*2,09*	*0,76*	*0,57*
after	*14*	*46,14*	*0,22*	*0,14*	*0,02*

Throughout the day another consequence of the room's acoustic refurbishment is revealed at the Baumberge Schule. The attenuation of the classroom not only changed the average level, it also changed its distribution and/or progression beyond the morning. Once again the influence of the room acoustics becomes visible, particularly in the case of the basic SPL $L_{A95.5min}$. While the level reduction between the un-refurbished and the refurbished classroom in the working SPL was constant to some degree, albeit somewhat less in the first two lessons (Fig. 5.62), it increased steadily in the case of the basic SPL beyond the morning (Fig. 5.63). The associated regression diagrams (Fig. 5.64 and 5.65) show that the increase of the working SPL beyond the morning was greatly reduced by the refurbishment. In fact the normal increase in the basic SPL was largely eliminated. Whether this represents another indication of the absence of fatigue will be clarified subsequently (see section 5.2.2). This phenomenon also becomes evident if compares the average values of the basic SPL for the whole teaching units instead of for the 5-min time slices ($L_{A95,45min}$) (Fig. 5.66).

On average the basic SPL at the Baumberge Schule fell by 8.8 dB(A). This is an astonishing value from several perspectives. Firstly it is already relatively close to the 10-dB mark that is generally rated as half the perceived volume. In short, the background noise level at the Baumberge Schule was subjectively judged to be half as loud after the refurbishment as before the refurbishment.

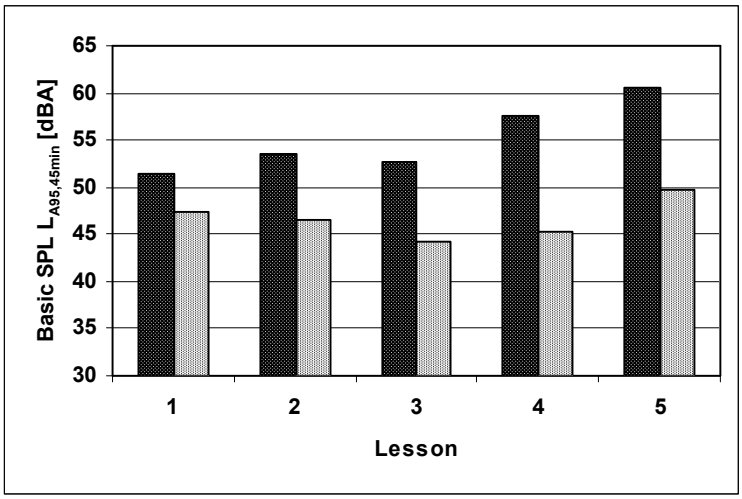


Fig. 5.66 Average basic SPL from $L_{A95.45min}$ before (■) and after (□) the refurbishment (Baumberge Schule; all lessons; sorted according to lessons on the day)

This is particularly surprising because the Baumberge Schule with its pedagogical anti-noise concept and its deliberate incorporation of quiet methods of working was already a quiet school before the refurbishment. Thus expectations shifted somewhat with regard to the noise reduction within the context of the level reduction which was physically achievable with the installation of the absorption surface:

V	*225.8*	*A = 0.163 * V/T*
m²		*(Sabine)*
RT_{before}	*0.75 s*	
RT_{after}	*0.35 s*	⇨ A_{before} = 49.07 m^2
		⇨ A_{refurb} = 105.16 m^2
		ΔI = 10 lg (A1 + ΔA)/A1[dB]
		⇨ **ΔI_{calc} = 3.31 dB**

However, on the other hand, the contribution of the pupils to this level reduction is evident. More than half of the achieved effect comes not from the physical absorption but from the pupil behaviour. While the children in the Baumberge Schule were already unusually quiet and well-disciplined prior to the intervention, they reacted immediately and surprisingly obviously to the changed learning environment and reduced the background volume in the lessons by more than double the mathematically predicted value overall.
For the monitored conditions at the Baumberge Schule the relationship between room acoustics and noise development in teaching is thereby clearly demonstrable. However, how is this relationship manifested in the Grundschule Stichnathstraße with considerably more variables (different pupils, teachers, year groups)? Are there any possible links between the different room characteristics of the two floors and the noise level in the classroom? Especially the difference in room acoustics between the

classrooms on the ground floor and those on the top floor are considerably less than those produced by the refurbishment in the Baumberge Schule.
The results are surprising. In fact all eight classes at the Grundschule Stichnathstraße reveal the same relationships as in the Baumberge Schule. Irrespective of teaching staff and age group, the rooms on the top floor with 0.1 to 0.3 s shorter reverberation times 'produce' lower working SPL and particularly basic SPL than the ground floor rooms (Fig. 5.67 and 5.68). The impact of these shorter reverberation times is once again particularly clearly seen in the shift in the frequency of the SPL classes in the case of the basic SPL! The room acoustic quality of the classrooms at the Grundschule Stichnathstraße – in all year groups and with all teachers – provide quieter or louder basic acoustic working conditions.

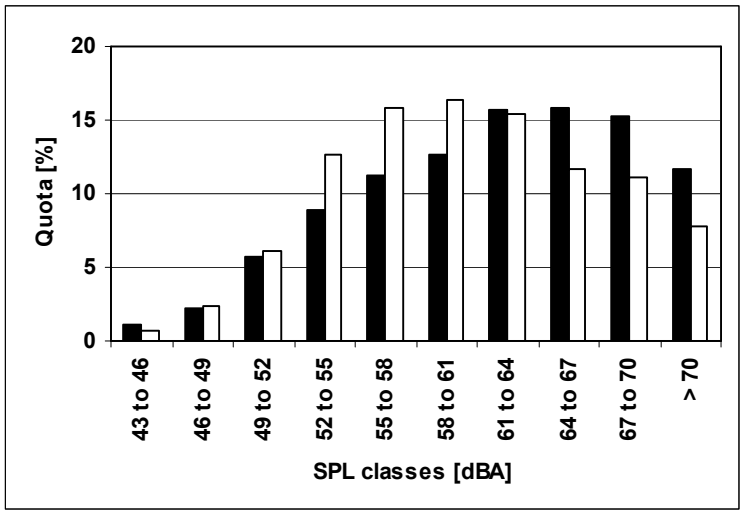


Fig. 5.67 Frequency distribution of the working SPL $L_{Aeq,5min}$ on the ground floor (■) and on the top floor (□) (Stichnathstraße; all lessons, across year groups)

In order to at least exclude the uncertainty factor of the year group it is worth looking at the second and third classes, of which one each is taught on the top floor and on the ground floor. These individual comparisons are, however, not without problems because in contrast to the Baumberge Schule the noise level here may also depend on the different styles of the teaching staff, on different student behaviour or on other factors. Despite this there is a visible relationship, while as expected, there is nothing like as uniform a picture as in the Baumberge Schule.

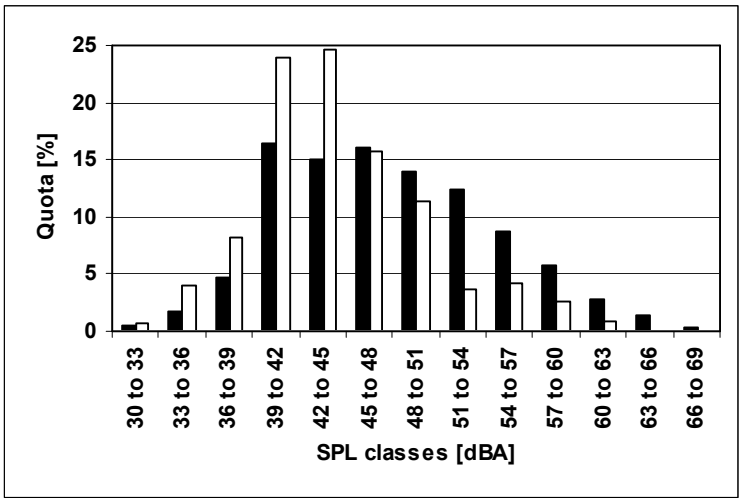


Fig. 5.68 Frequency distribution of the basic SPL $L_{A95.5min}$ on the ground floor (■) and on the top floor (□) (Stichnathstraße; all lessons, across year groups)

The frequency distribution of the noise level (Fig. 5.69 by 5.72) verifies that in accordance with the general trend, lessons on the top floor in both year groups featured lower values overall for both the working SPL and the basic SPL than on the ground floor. Particularly the high SPL classes occurred relatively seldom.

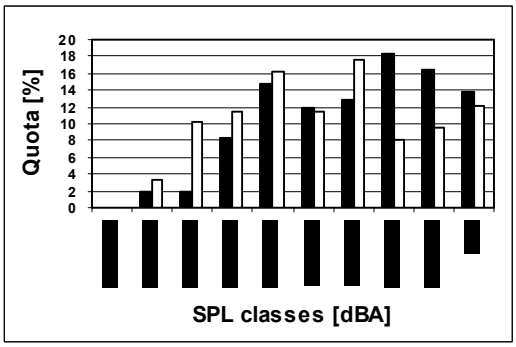


Fig. 5.69 Frequency distribution of the working SPL $L_{Aeq,5min}$ on the ground floor (■) and on the top floor (□) (Stichnathstraße; all lessons, year 2 classes)

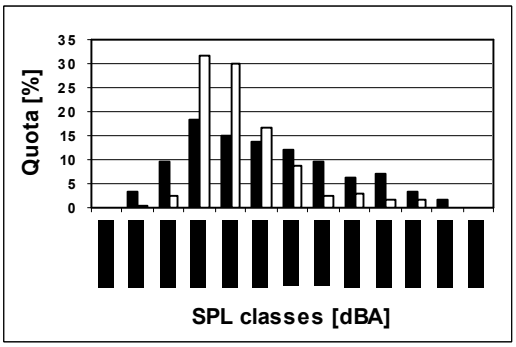


Fig. 5.70 Frequency distribution of the basic SPL $L_{A95.5min}$ on the ground floor (■) and on the top floor (□) (Stichnathstraße; all lessons, year 2 classes)
Median $L_{A95:}$ Ground floor: 45.5 dB(A)
Top floor: 43.2 dB(A)

However, the opposite result in the working SPL of the year-three class (Fig. 5.71) again shows the problem of comparability. Is the higher level on the top floor due to the "ineffectiveness" of the room acoustics or did the teacher simply teach differently (or perhaps has a very loud voice?)? Nevertheless in the year three classes too, the basic SPL was less frequently within the > 51 dB(A) range on the top floor than on the ground floor (Fig. 5.72) and the year-two and -three groups featured similar behaviours in terms of the median. In both cases the median of the basic SPL in the

rooms with the shorter reverberation time was approx. 2 dB lower than on the ground floor.

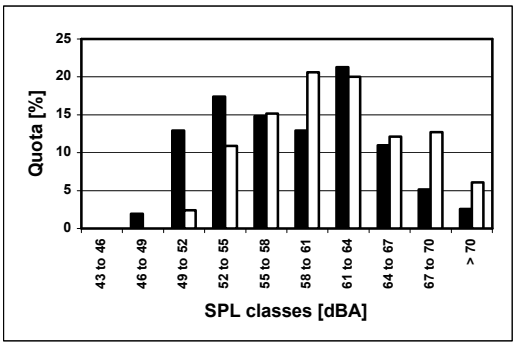


Fig. 5.71 Frequency distribution of the working SPL $L_{Aeq,5min}$ on the ground floor (■) and on the top floor (□) (Stichnathstraße; all lessons, year three classes)

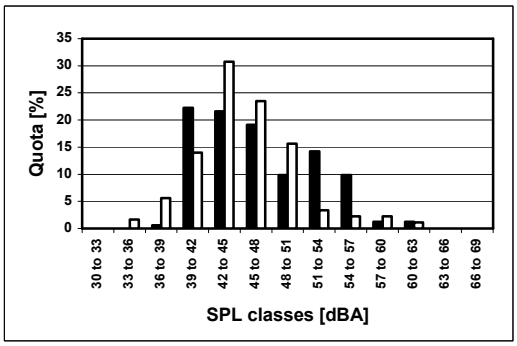


Fig. 5.72 Frequency distribution of the basic SPL $L_{A95.5min}$ on the ground floor (■) and on the top floor (□) (Stichnathstraße; all lessons, year three classes)
Median $L_{A95:}$ Ground floor: 46.2 dB(A)
Top floor: 44.6 dB(A)

This is no accident as is verified by the systematic comparison of all classrooms in the Grundschule Stichnathstraße. To minimise the influence of the teachers, the basic SPL as is used as the reference value. Figure 5.73 shows in the results a direct linear relationship between the basic SPL and the reverberation time: In the classrooms with reverberation times between 0.6 and 0.75 s. the children learn against an approx. 5 dB louder background basic SPL than their contemporaries in the classrooms with reverberation times of between 0.4 and 0.5 s.

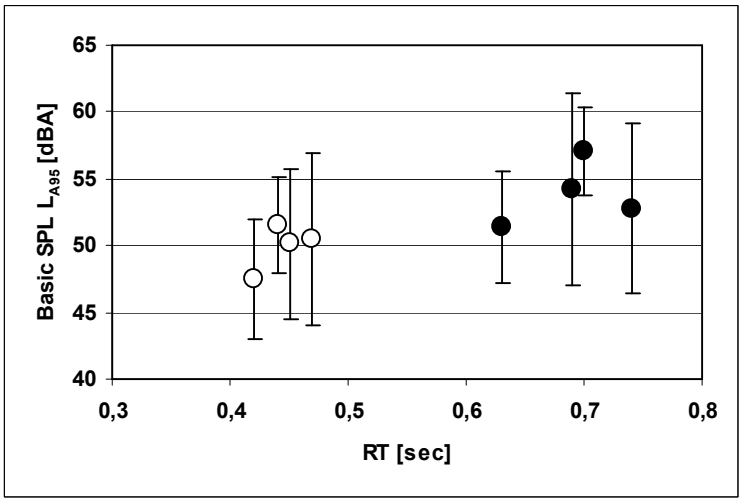


Fig. 5.73 Basic SPL L_{A95} in relation to the reverberation time of the classrooms for the Grundschule Stichnathstraße; all ground floor classes (●) and top floor classes (○)

This clearly shows that the latest version of the German standard DIN 18041 "Hörsamkeit in kleinen bis mittelgroßen Räumen" (audibility in small to medium-sized

rooms) offers scope for very different room acoustic qualities within classrooms with its specifications for liberal versus strict designs.
The picture becomes clearer if we relate the measured basic SPLs to the respective Speech Transmission Indices STI. The classrooms with "very good" speech intelligibility (STI > 0.75) come off visibly better than their "good" counterparts on the ground floor (0.60 < STI < 0.75) (Fig. 5.74). The regression between the two values is strikingly good (Fig. 5.75).
The picture matches the results from the Baumberge Schule. The reduction in the measured basic SPL was also due to considerably improved speech intelligibility. Figure 5.76 shows the change in the overall view with the values from the Grundschule Stichnathstraße. Although Class 2b in the Baumberge Schule started out with an already considerably lower basic SPL and with a comparatively conscious pedagogical concept, a discernible level reduction was still achieved, providing almost studio quality speech intelligibility (STI > 0.85).

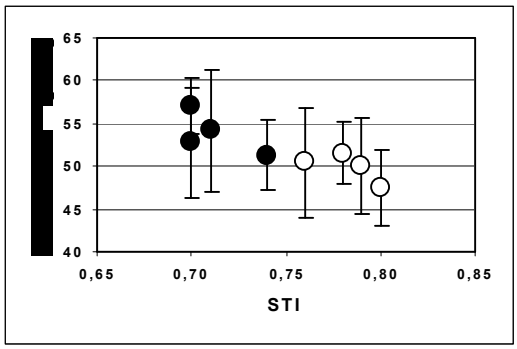


Fig. 5.74 Basic SPL L_{A95} relating to the STI of the classrooms for the Grundschule Stichnathstraße; all ground floor classes (●) and top floor classes (●)

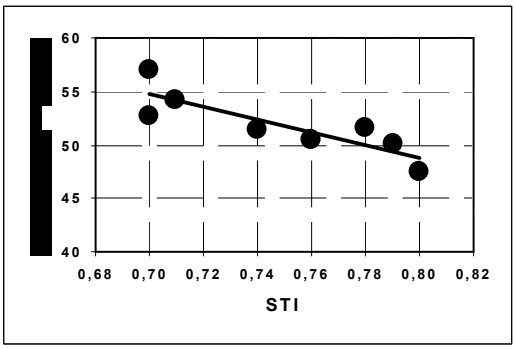


Fig. 5.75 Regression for Fig. 5.74

*Y = A + B*X*

N	*A*	*B*	*R*	*R²*
8	*96.72*	*-59.98*	*0.85*	*0.73*

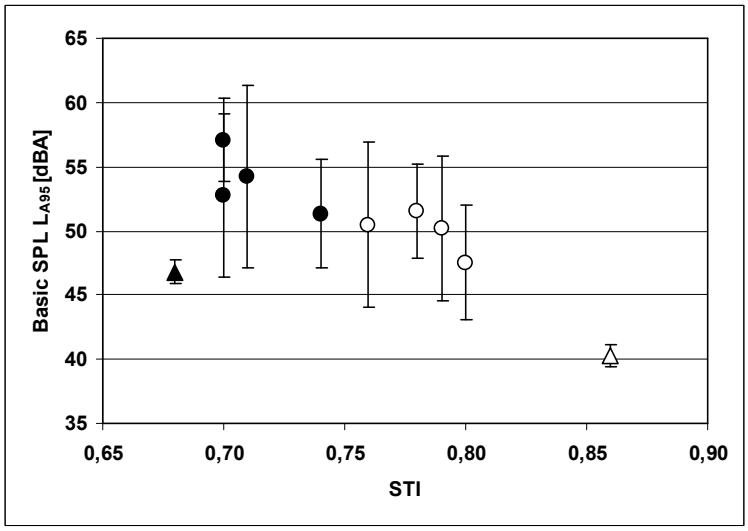


Fig. 5.76 Basic SPL L_{A95} relating to the STI for the Grundschule Stichnathstraße; all ground floor classes (●) and top floor classes (○), and Baumberge Schule before (▲) and after (Δ) refurbishment

The relationship between the room acoustic properties of the classroom and the noise level are therefore reliably verified with the present data. Proceeding from the pedagogical or social conditions at the outset, this phenomenon occurs to different degrees in the two schools. However it is evident in all classrooms. The dependence on the teaching noise level on the room acoustics is surprisingly linear. The finding fits well with the results from previous investigations using other data records (see OBERDÖRSTER AND TIESLER, 2004). There too, one can see a linear reduction of the basic SPL L_{A95} by around 1.6 to 2.0 dB per 0.1 s reduced reverberation time.

5.2.1.2 Analysis of the noise level in relation to the teaching method

Unlike the previous question, the investigation of the interdependence of noise level and teaching methods provides less clear results. A first comparison of the average working SPL $L_{Aeq,5min}$ for time slices with high and low shares of direct teaching shows at least for the Baumberge Schule that direct teaching-dominated time slices were generally quieter than others (Fig. 5.77). The measured average value of between 55 and 60 dB(A) approximately corresponds to an adult speaking voice in normal, not excessively strained conversation. This a further indication of the calm working climate in the Baumberge Schule in which during direct teaching phases the teacher is standing by the board and is not forced to speak in a raised voice for long periods. In fact the general noise level in the Grundschule Stichnathstraße in time slices dominated by direct teaching-is considerably higher than in the Baumberge Schule. However, there is no clear difference as compared to direct teaching periods. Whether in any case the noise level determined from all classes in the Grundschule Stichnathstraße is at all helpful for this question appears doubtful. Once again, one needs to take into account the many uncertainty factors (teacher preferences, pupil behaviour etc.). Furthermore the project report for the study "Lärm in Bildungsstätten" (noise in educational establishments) in its first evaluation of the noise level showed a clear year-group dependency (see SCHÖNWÄLDER ET AL., 2004).

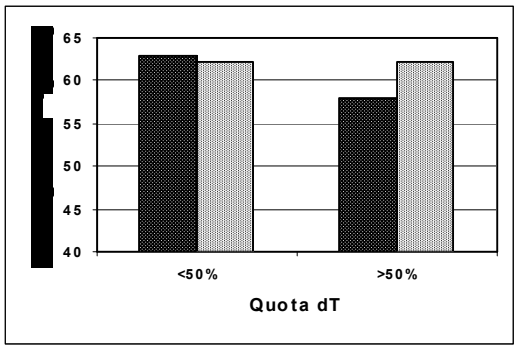


Fig. 5.77 Average working SPL $L_{Aeq,5min}$ for time slices with high and low shares of dT, Baumberge Schule (▓) and Schule Stichnathstraße (▒)

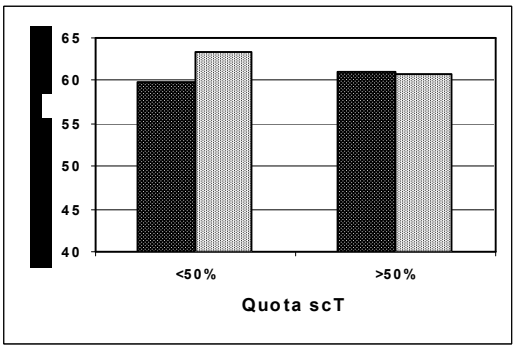


Fig. 5.78 Average working SPL $L_{Aeq,5min}$ for time slices with high and low shares of scT, Baumberge Schule (▓) and Schule Stichnathstraße (▒)

If one remains therefore with the reliable data record of the Baumberge Schule, the following phenomenon emerges with regard to teaching periods characterised by student-centred teaching methods. On average, these are louder than other working

phases (Fig. 5.78). (Once again this trend is not confirmed by the average values from the Grundschule Stichnathstraße.)

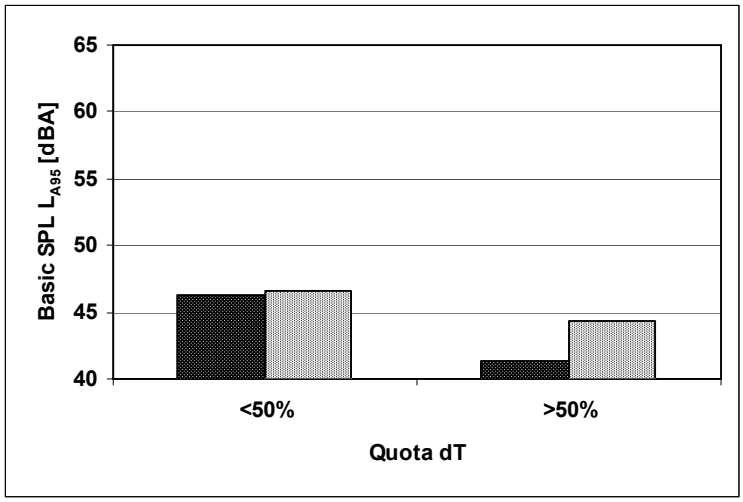


Fig. 5.79 Average basic SPL $L_{A95.5min}$ for time slices with high and low shares of dT, Baumberge Schule (▓) and Schule Stichnathstraße (▒)

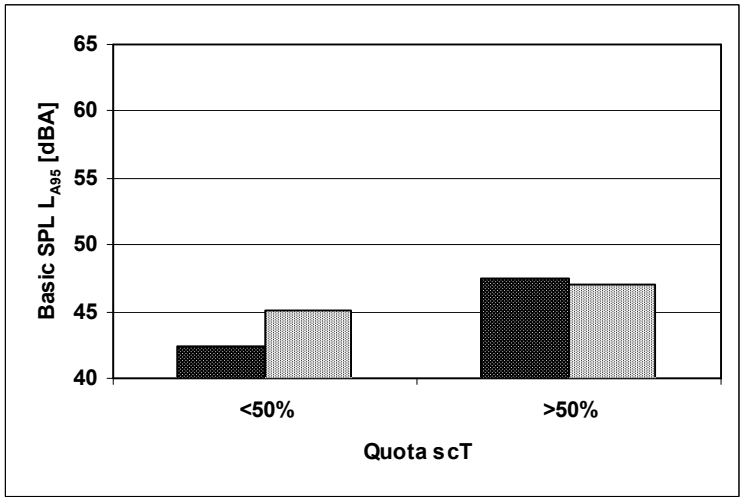
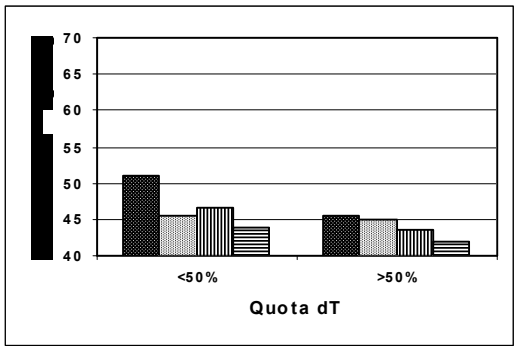


Fig. 5.80 Average basic SPL $L_{A95.5min}$ for time slices with high and low shares of scT, Baumberge Schule (▓) and Schule Stichnathstraße (▒)

The impact of the teaching method in the Baumberge Schule on the noise level is not only visible in the working SPL but also in the basic SPL. This is also clearer than expected. In the case of direct teaching the basic SPL falls compared to other teaching methods by more than 5 dB to 42 dB(A) (Fig. 5.79) – another confirmation of the quiet school culture typical of Baumberge. During student-centred working phases, however, the basic SPL climbs to levels of around 47 dB(A) (Fig. 5.80). Astoundingly, the same trends are found in the data record from the Grundschule Stichnathstraße. Does the Grundschule Stichnathstraße thereby provide circumstantial evidence that this relationship between teaching method and basic SPL is generally valid and can be assumed for other schools or is this also a consequence of the similar pedagogical concept?



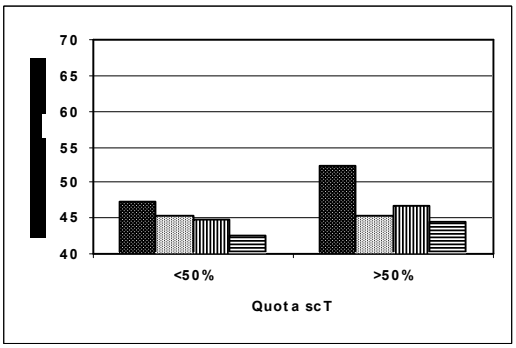


Fig. 5.81 Average basic SPL $L_{A95,5min}$ for time slices with high and low shares of dT, year 1 cl (▓), year 2 cl (▓), year 3 cl (‖) and year 4 cl (▓)

Fig. 5.82 Average basic SPL $L_{A95,5min}$ for time slices with high and low shares of scT, year, 1. cl (▓), 2. cl (▒), 3. cl (‖) and year 4 cl (═)

In fact the suspicion is supported if one views the data organised according to year group. Figures 5.81 and 5.82 confirm the rise and fall in the basic SPL in relation to the teaching method. However, the cause of this cannot be determined based on the present data. What role does the time of day play (see 5.2.1.1)? Does the age of the pupils and therefore their working behaviour play a decisive role? The clear difference between the year-one and year-four groups appear to concur with this assumption.
This relationship is not proven for the working SPL in the Stichnathstraße if one breaks down the data according to year group. Overall the results of this investigation remain unsubstantiated. Without further differentiation, particularly of the role of the room acoustics in this question, it is not possible to substantiate any general tendencies apart from the aforementioned assumptions.

5.2.1.3 Analysis of the noise level in relation to TgS and SgS shares of speech

As in the previous section, a lesson-based compilation of individual values does not help in the analysis of the noise level in relation to shares of speech.

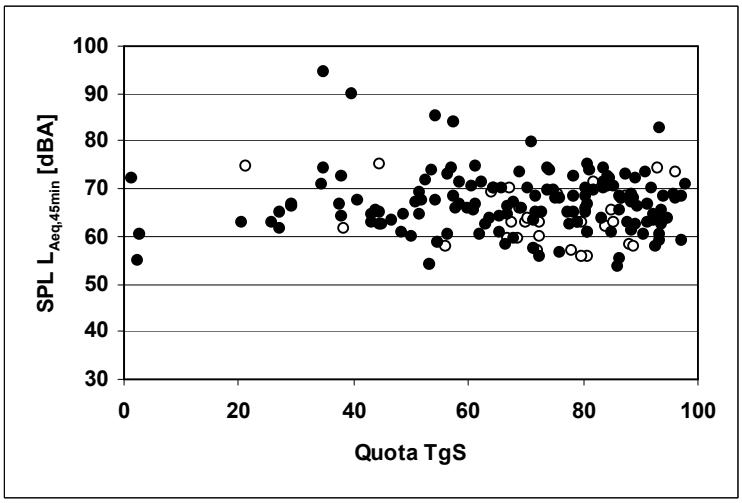


Fig. 5.83 Working SPL $L_{Aeq,45min}$ in relation to the teacher speech share over the lesson, Grundschule Stichnathstraße (●) and Baumberge Schule (○)

With regard to teacher-generated speech and its impact on the working SPL $L_{Aeq,45min}$Figure 5.83 clearly shows again that the values in both schools shift by a similar amount. Ultimately, however, only a clumping is visible. Neither this overview nor a separate observation of each school reveals a relationship and/or a regression between the two values (Fig. 5.84 and 5.85).

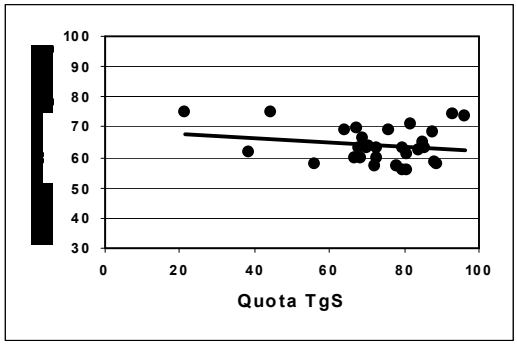


Fig. 5.84 Working SPL $L_{Aeq,45min}$ in relation to the teacher speech share over the lesson, Baumberge Schule

*Y = A + B*X*

N	*A*	*B*	*r*	*r²*
30	*69.10*	*-0.07*	*0.19*	*0.04*

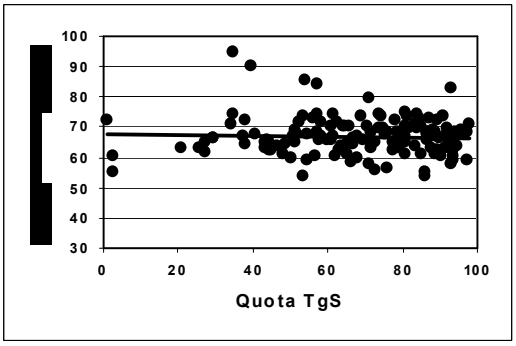


Fig. 5.85 Working SPL $L_{Aeq,45min}$ in relation to the teacher speech share over the lesson, Grundschule Stichnathstraße

*Y = A + B*X*

N	*A*	*B*	*r*	*r²*
142	*67.75*	*-0.01*	*0.04*	*0.00*

The same picture appears in relation to the pupil speech shares. The tables are shown purely for the sake of transparency (Fig. 5.86 to 5.88).

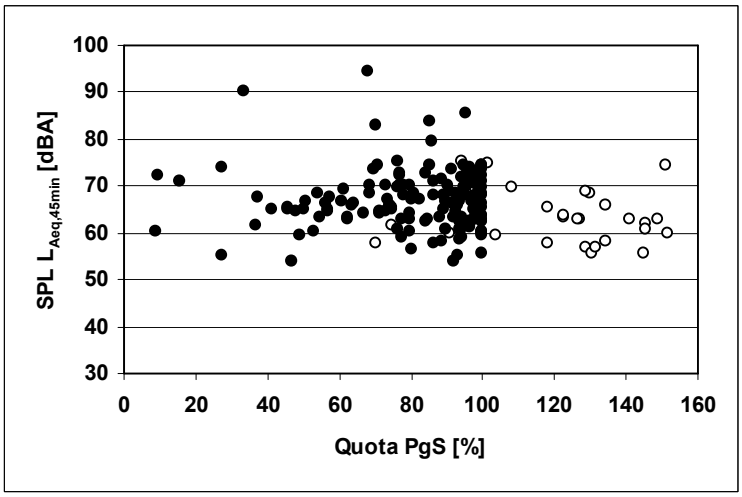


Fig. 5.86 Working SPL $L_{Aeq,45min}$ in relation to the pupil speech shares over the lesson, Grundschule Stichnathstraße (●) and Baumberge Schule (○)

It is not possible to conclude a relationship between student-generated speech and the lesson-related working SPL $L_{Aeq,45min.}$ The only clear difference is in the behaviour of the observers in the two schools. While in the Baumberge Schule the share of

student-generated speech could exceed 100 % because different speech features were recorded in parallel, the shares of speech in the Grundschule Stichnathstraße are all recorded sequentially.

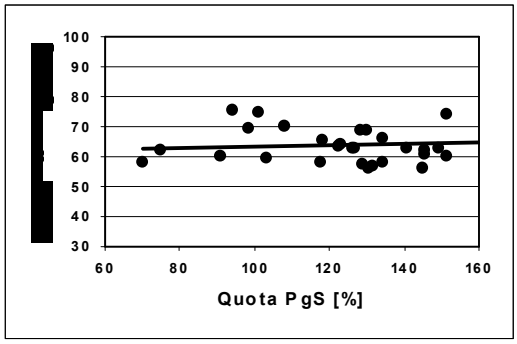


Fig. 5.87 Working SPL $L_{Aeq,45min}$ in re-lation to the student-generated speech share over the lesson, Baumberge Schule

*Y = A + B*X*

N	*A*	*B*	*r*	*r²*
30	*60.63*	*0.03*	*0.11*	*0.01*

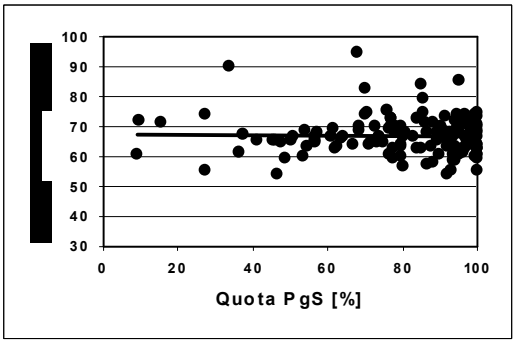


Fig. 5.88 Working SPL $L_{Aeq,45min}$ in re-lation to the student-generated speech share over the lesson, Grundschule Stichnathstraße

*Y = A + B*X*

N	*A*	*B*	*r*	*r²*
142	*67.37*	*-0.01*	*0.02*	*0.00*

If one uses the operationalised 5-min units instead of the lesson-based average value, one is deliberately comparing time units with similar and/or the same structure and the picture changes. One can therefore assume from Figures 5.89 and 5.90 that the teaching phases predominantly characterised by teacher-generated speech, at least in the Baumberge Schule, were quieter than those in which the teacher spoke little, while time slices in which student-generated speech dominated were considerably louder than those in which pupils spoke little.

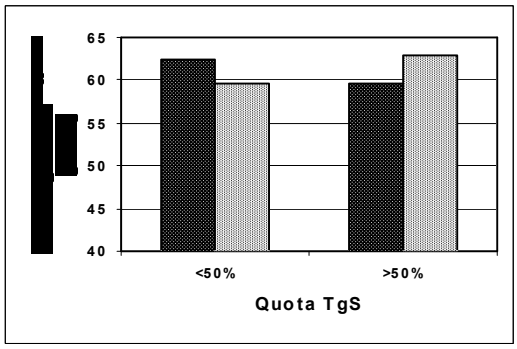


Fig. 5.89 Average working SPL $L_{Aeq,5min}$ for time slices with high and low shares of TgS, Baumberge Schule (▓) and Schule Stichnathstraße (▒)

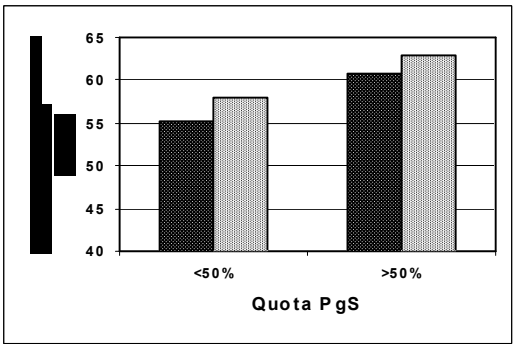


Fig. 5.90 Average working SPL $L_{Aeq,5min}$ for time slices with high and low shares of SgS, Baumberge Schule (▓) and Schule Stichnathstraße (▒)

One ought to note once again that time slices in which there is little teacher-generated speech are not to be equated with more frequent student-generated

speech. This relationship is only found in the case of student-generated speech at the Grundschule Stichnathstraße. It is tempting to speculate again about the pedagogical approach of the staff at the Baumberge Schule that enables the teacher to speak undisturbed. The disciplined listening of the children would then be the parameter for the teacher's comparatively quiet speech volume. This effect does not occur in the Grundschule Stichnathstraße. Different pupil social behaviour would be one explanation, if it forced the teacher to gain the listener's attention in a raised voice. The problem of this data record has, however, already been addressed in the previous section 5.2.1.2.
Like the teaching method, the relationship of working SPL and shares of speech is also found with the basic SPL. Only a low basic SPL in TgS < 50 % time slices at the Baumberge Schule fails to conform to the trend.
No new evidence is revealed if the Grundschule Stichnathstraße data is broken down according to year group. Only the year-four class is significant. In this case the difference of the working SPL between teaching phases with low shares of teacher-generated speech and phases with high shares of teacher-generated speech is particularly high (Fig. 5.91). This might be an indication of more 'mature' pupil behaviour, i.e. working in a more concentrated and attentive manner in periods of listening or quiet, with participation and involvement during discussion phases. This difference is also reflected in the basic SPL. This age-dependent effect has already been addressed in section 5.2.1.2 .

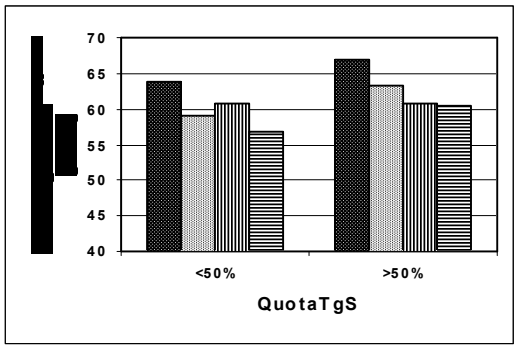


Fig. 5.91 Average working SPL $L_{Aeq,5min}$ for time slices with high and low shares of TgS, year 1 cl (▒), year 2 cl (▒), year 3 cl (‖) and year 4 cl (▒)

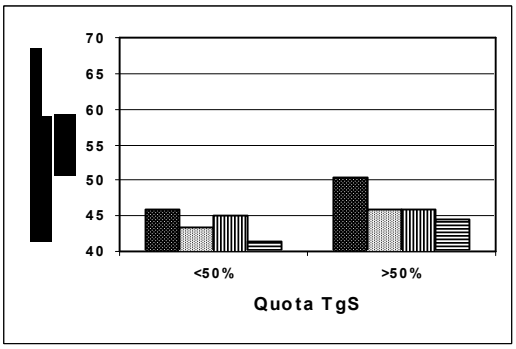


Fig. 5.92 Average basic SPL $L_{A95,5min}$ for time slices with high and low shares of TgS, year 1 cl (▒), year 2 cl (▒), year 3 cl (‖) and year 4 cl (▒)

Overall the summary equates with the summary of the previous section. Any other reliable predictions would require the inclusion of further parameters, particularly that of room acoustics.

5.2.1.4 Analysis of the noise level depending on selected filter combinations

On the basis of the existing analyses it is now possible to ask how the working and the basic SPLs in the classroom change based on the room acoustic working environment (Filter 1) during specific working phases (Filter 2). Does the basic ergonomic condition of the room acoustics actually have different effects during different teaching methods, as formulated in hypothesis 3?

A lesson-based analysis with the average values based on the 5-min units is the starting point of the observation. Figures 5.93 by 5.96 show the clear general reduction in the $L_{Aeq,45min}$ and in the $L_{A95,45min}$ caused by the different room acoustic conditions both for the Baumberge Schule and for the Grundschule Stichnathstraße. The respective regression of the individual analyses however is extremely weak and this method of observation therefore reveals no initial dependency on the teaching method.

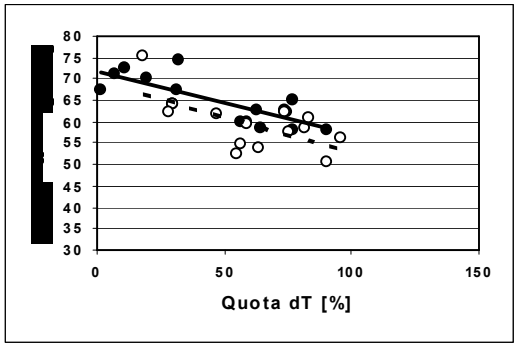


Fig. 5.93 Working SPL $L_{Aeq,45min}$ in relation to the percentage of dT time before (●) and after (○) the refurbishment, Baumberge Schule

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*
●	*16*	*69.48*	*-0.11*	*0.70*	*0.49*
○	*15*	*64.34*	*-0.13*	*0.72*	*0.52*

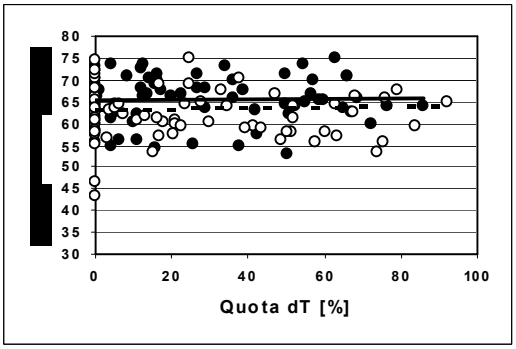


Fig. 5.94 Working SPL $L_{Aeq,45min}$ in relation to the percentage of dT time on the ground floor (●) and top floor (○), Grundschule Stichnathstraße

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*
●	*66*	*64.11*	*0.00*	*0.00*	*1.75*
○	*75*	*60.87*	*0.013*	*0.07*	*0.01*

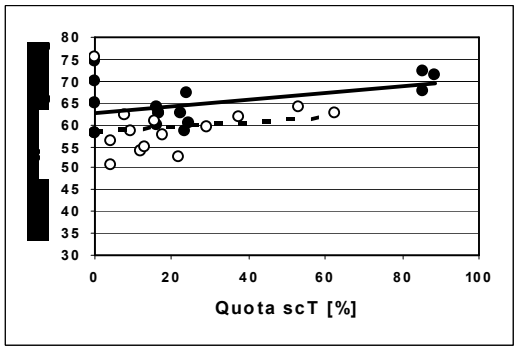


Fig. 5.95 Working SPL $L_{Aeq,45min}$ in relation to the percentage of scT time before (●) and after (○) the refurbishment, Baumberge Schule

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*
●	*16*	*61.67*	*0.08*	*0.52*	*0.27*
○	*15*	*55.59*	*0.05*	*0.23*	*0.05*

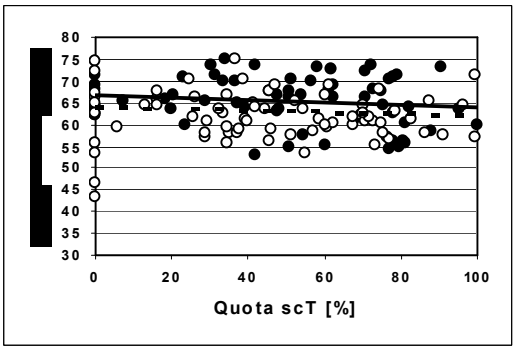


Fig. 5.96 Working SPL $L_{Aeq,45min}$ in relation to the percentage of scT time on the ground floor (●) and top floor (○), Grundschule Stichnathstraße

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*
●	*66*	*64.57*	*-0.01*	*0.05*	*0.00*
○	*75*	*61.45*	*-0.01*	*0.03*	*0.00*

It is worth noting once again in this context the personal pedagogical style of the observed teacher in the Baumberge Schule (see in detail section 5.1.2). Particularly

Figure 5.95 shows a relatively high percentage of time spent on student-centred teaching methods in both observation weeks. The noise level determined over the whole lesson is greatly influenced by the teaching method selected by this teacher. The (both weak!) regression rates show that lessons dominated by direct teaching were sometimes considerably quieter than those predominantly characterised by student-centred teaching (see Fig. 5.77 and 5.78). In the Grundschule Stichnathstraße for which the far greater data record with different classes and teachers is available, this observation is relativised as an individual case. In Figures 5.94 and 5.96, while the general calm due to the better room acoustics in the top floor of the school is evident, the average values do not suggest an equivalent dependency. A similar picture is gained for the basic SPL $L_{A95,45min}$ (Figs. 5.97 to 5.100).

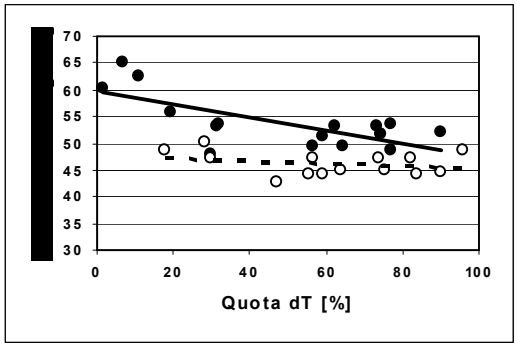


Fig. 5.97 Basic SPL $L_{A95,45min}$ depending on the percentage of dT time before (●) and after (○) the refurbishment, Baumberge Schule

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*
●	*16*	*52.33*	*-0.11*	*0.78*	*0.61*
○	*15*	*44.38*	*-0.07*	*0.64*	*0.41*

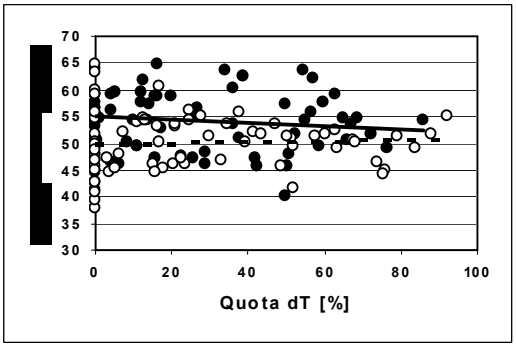


Fig. 5.98 Basic SPL $L_{A95,45min}$ in relation to the percentage of dT time on the ground floor (●) and top floor (○), Grundschule Stichnathstraße

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*
●	*66*	*49.62*	*-0.054*	*0.27*	*0.07*
○	*75*	*44.47*	*-0.01*	*0.06*	*0.00*

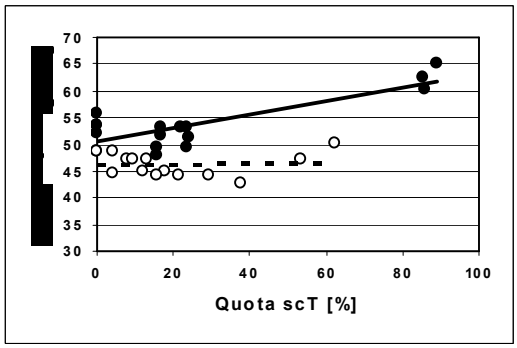


Fig. 5.99 Basic SPL $L_{A95,45min}$ depending on the percentage of scT time before (●) and after (○) the refurbishment, Baumberge Schule

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*

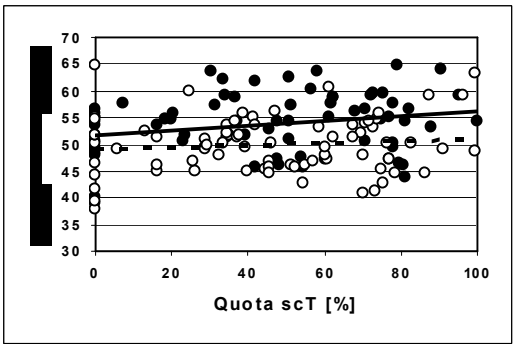


Fig. 5.100 Basic SPL $L_{A95,45min}$ in relation to the percentage of scT time on the ground floor (●) and top floor (○), Grundschule Stichnathstraße

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*

●	*16*	*43.68*	*0.11*	*0.83*	*0.69*	●	*66*	*45.77*	*0.05*	*0.28*	*0.08*
○	*15*	*38.71*	*0.08*	*0.60*	*0.36*	○	*75*	*43.35*	*0.02*	*0.18*	*0.03*

In the case of the basic SPL itself, the teacher observed at the Baumberge Schule creates an extraordinarily quiet learning and working atmosphere of less than 40 dB(A) in her predominantly direct-form lessons with several average values of around 45 dB(A) after the refurbishment. The differences in the basic SPL between these direct and the less frequent student-centred lessons are comparably high. The somewhat oddly assorted data record from the Grundschule Stichnathstraße does not reveal such a relationship. However the analysis of the basic SPL in both schools does provide initial circumstantial evidence that the level reduction not only depends on the room acoustics, but also on the teaching method. Although the averaging of whole lessons limits the precision of the analysis and the present regression is once again rather weak, the result is the same in all four cases (Fig. 5.97 to 5.100): The reductions of the basic SPL $L_{A95,45min}$ fall further in lessons with a high percentage of student-centred teaching time in both schools than in lessons with a high percentage of direct teaching time!

It seems sensible to assume that the acoustic result for this room is created not only by the reduction of the background volume due to the installation of an additional absorption surface but also particularly by the improved speech intelligibility in the classroom. This enables qualitatively better communication due to a clearer speech signal. Both the teachers and particularly the children, to whom in any case higher signal-to-noise ratios are assigned than adults (see section 2.1), can therefore communicate with one another without raising their voices.

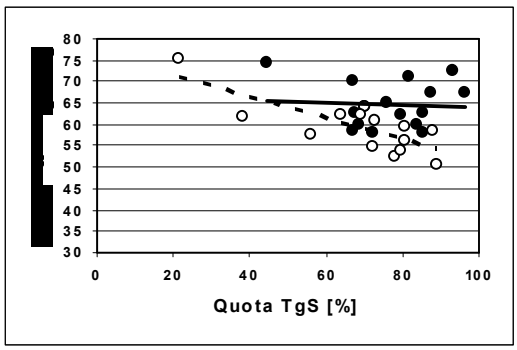


Fig. 5.101 Working SPL $L_{Aeq,45min}$ in relation to the percentage of TgS before (●) and after (○) the refurbishment, Baumberge Schule

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*
●	*16*	*62.66*	*0.02*	*0.04*	*0.00*
○	*15*	*66.14*	*-0.14*	*0.66*	*0.43*

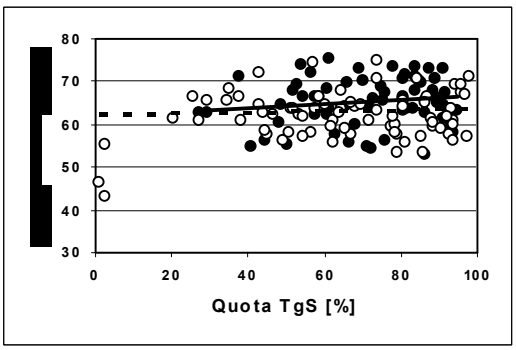


Fig. 5.102 Working SPL $L_{Aeq,45min}$ in relation to the percentage of TgS on the ground floor (●) and top floor (○), Grundschule Stichnathstraße

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*
●	*66*	*57.17*	*0.09*	*0.31*	*0.09*
○	*75*	*56.18*	*0.07*	*0.36*	*0.13*

The assumption that this actually occurs in the present lessons is supported by the knowledge that in both schools the level-reducing effect of the improved room acoustics is clearly related to the percentage of times of teacher and/or student speech. The more talking that occurs in individual lessons (be it by pupils or teachers) the clearer the difference of the average working and/or basic SPL (Fig.

5.101-5.108). The vicious circle or "Lombard-effect" - "if one person speaks louder, the next person has to speak louder etc.” is broken.

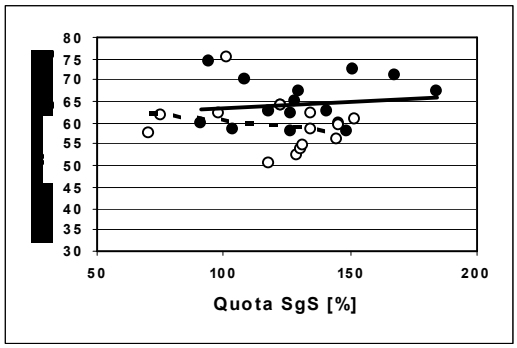


Fig. 5.103 Working SPL $L_{Aeq,45min}$ in relation to the percentage of SgS time before (●) and after (○) the refurbishment, Baumberge Schule

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*
●	*16*	*56.49*	*0.06*	*0.28*	*0.08*
○	*15*	*61.15*	*-0.04*	*0.24*	*0.06*

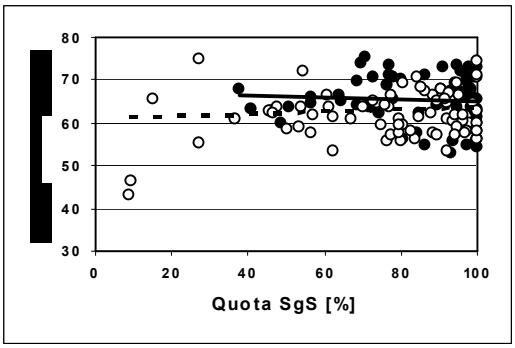


Fig. 5.104 Working SPL $L_{Aeq,45min}$ in relation to the percentage of SgS time on the ground floor (●) and top floor (○), Grundschule Stichnathstraße

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*
●	*66*	*59.79*	*0.05*	*0.16*	*0.02*
○	*75*	*55.82*	*0.07*	*0.32*	*0.10*

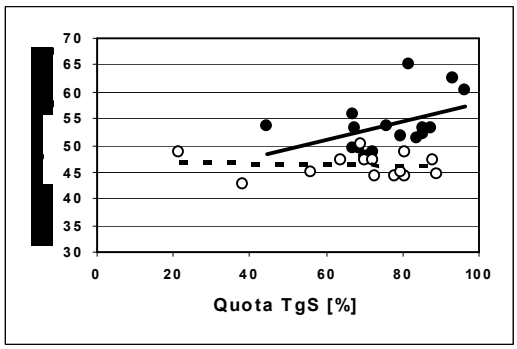


Fig. 5.105 Basic SPL $L_{A95,45min}$ depending on the percentage of TgS time before (●) and after (○) the refurbishment, Baumberge Schule

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*
●	*16*	*38.51*	*0.11*	*0.31*	*0.09*
○	*15*	*43.48*	*-0.05*	*0.37*	*0.13*

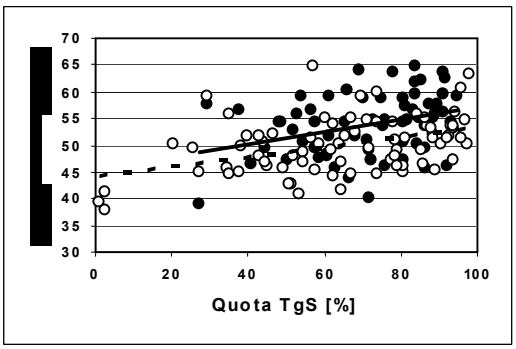


Fig. 5.106 Working SPL $L_{A95,45min}$ in relation to the percentage of TgS time on the ground floor (●) and top floor (○), Grundschule Stichnathstraße

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*
●	*66*	*40.04*	*0.11*	*0.38*	*0.14*
○	*75*	*39.85*	*0.06*	*0.45*	*0.20*

The circle is completed with a look at working phases. The data record from the Baumberge Schule provides the key to a more accurate comparison thanks to its monitored and therefore comparable basic conditions. Also, although the Baumberge Schule did not contain not quite as many time units dominated by student-centred

teaching as might have been desirable, the data basis is sufficient to document the following relationship.

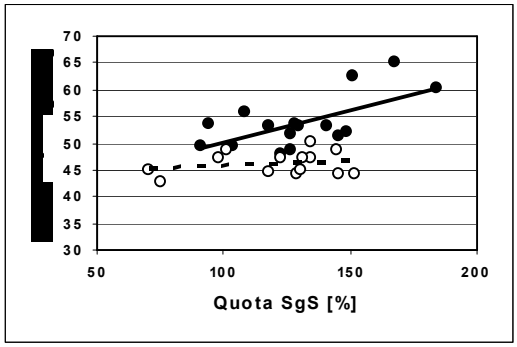


Fig. 5.107 Basic SPL $L_{A95,45min}$ depending on the percentage of SgS before (●) and after (○) the refurbishment, Baumberge Schule

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*
●	*16*	*33.36*	*0.10*	*0.58*	*0.34*
○	*15*	*40.91*	*-0.01*	*0.05*	*0.00*

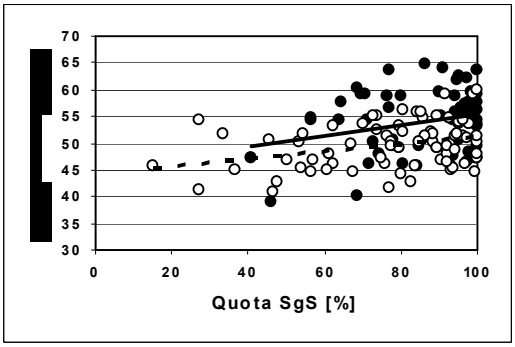


Fig. 5.108 Working SPL $L_{A95,45min}$ in relation to the percentage of SgS on the ground floor (●) and top floor (○), Grundschule Stichnathstraße

*Y = A + B*X*

	N	*A*	*B*	*r*	*r²*
●	*66*	*35.16*	*0.15*	*0.49*	*0.24*
○	*75*	*38.94*	*0.07*	*0.45*	*0.20*

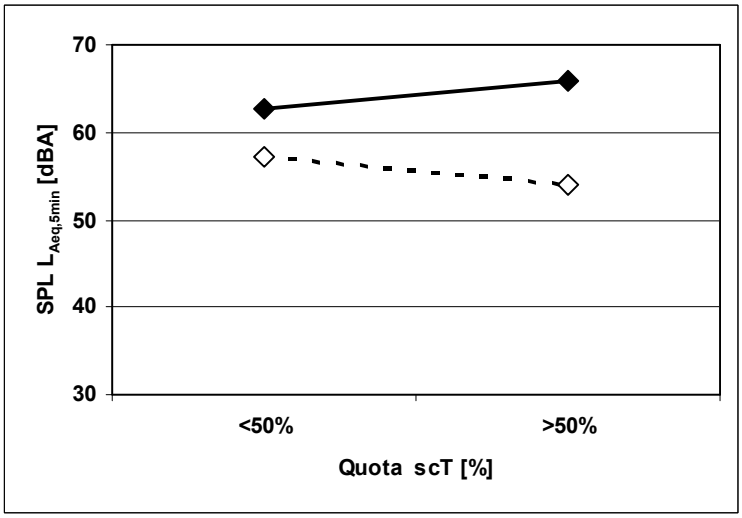


Fig. 5.109 Working SPL $L_{Aeq,5min}$ in relation to the percentage of scT time before (●) and after (○) the refurbishment, Baumberge Schule

During student-centred working phases the ergonomic parameters affected both the working SPL (Fig. 5,109) and the basic SPL (Fig. 5.110) more clearly. In the case of both L_{Aeq} and L_{A95} the level reduction of over 12 dB achieved by room acoustic refurbishment in student-centred teaching phases was double that of direct teaching phases (here scT < 50 %; 5 dB)! If one reviews what has already been said about the expected physical level reduction of approx. 3.3 dB (see section 5.2.1.1) it is also clear that during the direct teaching phases the majority of the level reduction is actually achieved by the physical process of absorption. The impact on the speech

behaviour was also rather small in this teaching phase. During student-centred teaching phases, however, the acoustic working environment played a significant role for the speech and communication behaviour. Around 9 dB of the measured level reduction was due in this case to emissions, i.e. from changed behaviour on the part of the teacher and pupils. The basic acoustic ergonomic conditions for teaching are therefore a particularly significant factor for noise development in the classroom in the context of "modern" rather than teacher-centred teaching methods.

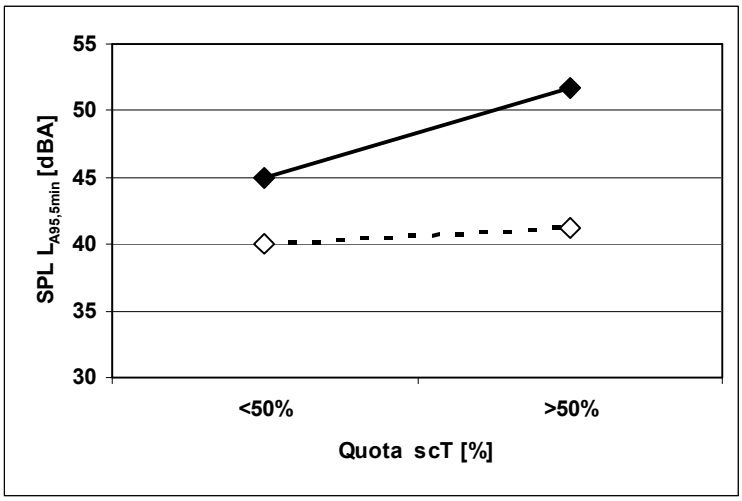


Fig. 5.110 Basic SPL $L_{A95,5min}$ depending on the percentage of scT time before (●) and after (○) the refurbishment, Baumberge Schule

The trend of the working SPL confirms once more the above assumption concerning the context of acoustic effects. The normal increase in the working SPL that marked the transition to student-centred teaching methods in the Baumberge Schule was reduced. Analysis of the 5-min units verifies that after the refurbishment the teaching units "scT > 50 %" actually tended to be quieter than their direct counterparts. One possible explanation is that the teacher is no longer speaking to the whole class from the board (i.e. needing to bridge a distance of some 6-7 m to pupils in the back row). Communication rather takes place over smaller distances (table group, working group). If the improved speech intelligibility eliminates the otherwise expected Lombard effect, however, all participants can communicate in low voices with no loss of intelligibility. The Baumberge Schule verifies that the extreme attenuation of the classroom with reverberation times of under 0.4 seconds enabled student-centred teaching phases to take place at a working SPL below that of an individual adult speaking voice. The trend of the basic SPL (Fig. 5.110) completes this picture. Here again the increased noise level normally associated with student-centred teaching phases was eliminated after the refurbishment.
The trends are equally evident from random samples in the Grundschule Stichnathstraße. However, due to the variety of uncertainty factors (different classes, year groups and particularly teaching staff) one cannot assume that an individual analysis based on the Stichnathstraße data record can deliver reliable results for this question. They are therefore not illustrated.

5.2.2 Heart rate analysis

5.2.2.1 Heart rate analysis in relation to the room acoustics

This section reports on the investigation of whether a relationship exists between room acoustic conditions and personal stress in comparable working situations.
The building characteristics of the Grundschule Stichnathstraße (see section 5.1.1) provide two different acoustic situations. The ground floor rooms have a RT > 0.5 s, while those on the top floor have a RT < 0.5 s. Of those involved in the investigation five people taught on the ground floor and eight people on the top floor and one of those teachers taught under both conditions. Figure 5.111 illustrates the average stress and the basic levels of activity in teaching. The average values of all participants vary by over 3 beats per minute. This indicates visibly less stress under better room acoustic conditions and in fact with regard to both the basic activation and to the average stress in teaching.

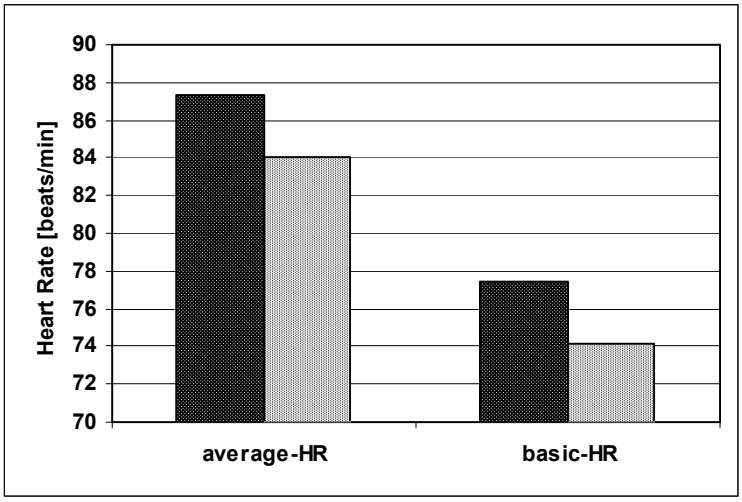


Fig. 5.111 Average stress (average-HR, average heart-rate value) and basic activation (basic-HR) in teaching for all teachers, grouped according to classrooms on the ground floor (▓) and top floor (▒); Grundschule Stichnathstraße

In each case the data represents the average values from 5-min time slices and lessons lasting at least 35 min, see Table 5.2.

Table 5.2 Overview of the number of test subjects (sub.) and analysed time slices

RT	Subject	Time slices
RT > 0.5	N = 5	486
RT < 0.5	N = 8	914

One of the participating teachers taught on the ground floor as well as on the top floor and is therefore included in both data records. The average stress values for this person alone give a similar picture, see Figure 5.112, although the difference is somewhat less. It supports the proposal however that under better room acoustic

conditions the basic activation as well as the stress is less. A possible objection to this interpretation may lie in the fact that the two classes were a year-one class and a year-three class. This question will be addressed again later.
Since the condition of an individual's cardiovascular system, determined e.g. by physical condition, affects the absolute heart rate value, it seems sensible to analyse and compare the average stress of an individual sorted according to the classroom in which they are teaching.
The result is shown in Figure 5.113. Here again one can see higher stress levels in those persons who have taught on the ground floor.

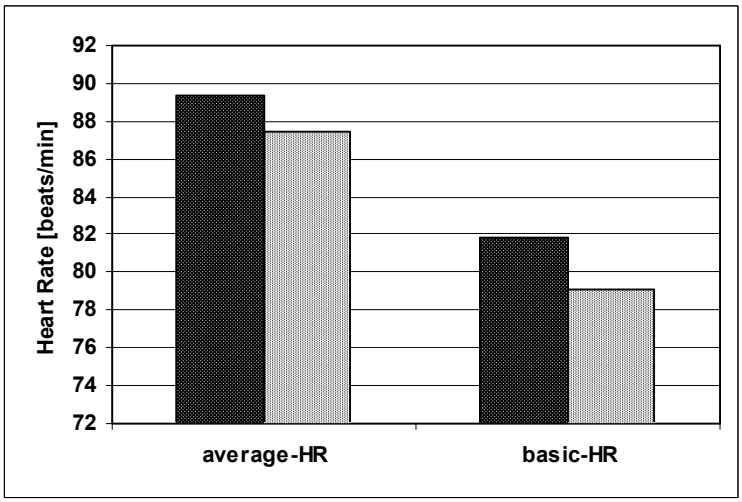


Fig. 5.112 Average stress for one person in the Grundschule Stichnathstraße who has taught under both conditions grouped according to classrooms on the ground floor (▓) and top floor (▒);

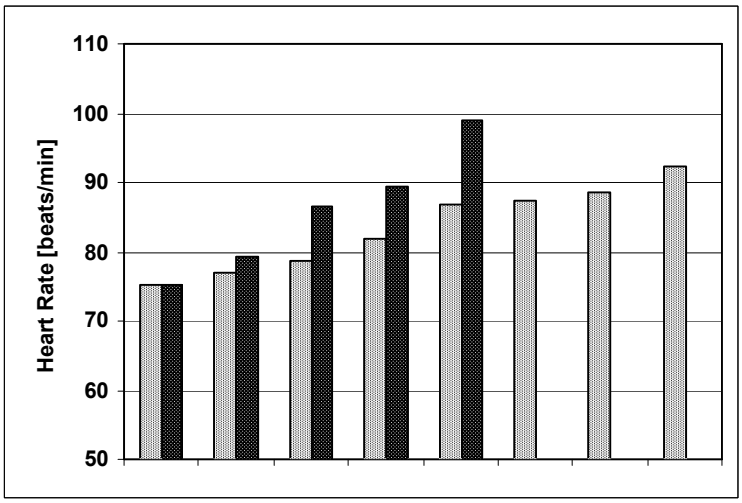


Fig. 5.113 Average stress of individual teachers, grouped according to classroom, RT > 0.5s (▓) and RT < 0.5s (▒); Grundschule Stichnathstraße

With one exception, a comparison of the basic activation (Fig. 5,114) shows the same picture. The ranking is exactly the same in both cases.

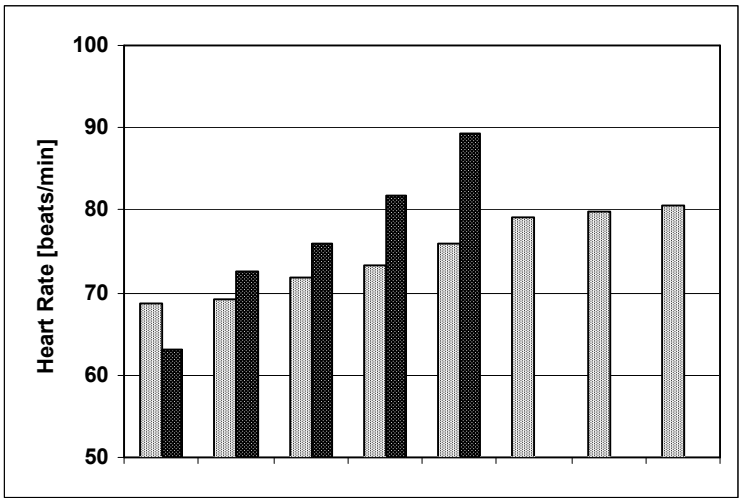


Fig. 5.114 Basic activation of individual teachers during teaching, grouped according to classroom, RT > 0.5s (▓) and RT < 0.5s (▒); Grundschule Stichnathstraße

There now follows a comparison with these results from the Grundschule Stichnathstraße of the teacher data from the Baumberge Schule. The comparison of the average stress and the basic activation in teaching is shown in Figure 5.115. Once again we see the same picture as in Figure 5.112.

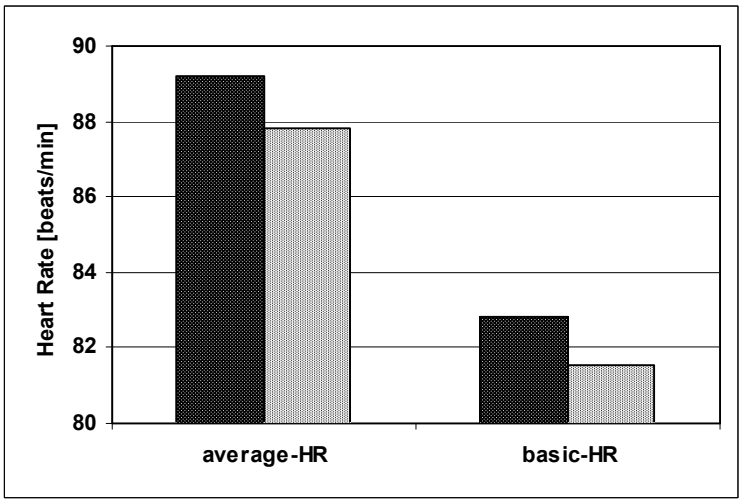


Fig. 5.115 Average stress (average-HR) and basic activation (basic-HR) in teaching, grouped according to room acoustics before (▓) and after (▒) the refurbishment; Baumberge Schule

The straightforward comparison of average values reflects a problem, particularly for data that is not normally distributed, as is the case with heart rate data. In this case it makes sense to examine the distribution of the data somewhat more closely. The distribution of both the average stress, also referred to by occupational science as the working pulse, and the basic activation are now analysed based on the 5-min time slices. The distribution of the average stress of all teachers at the Grundschule Stichnathstraße is shown in Figure 5.116. Figure 5.117 shows that of the individual

teacher at the Baumberge Schule. The values in both figures are grouped according to "good" (RT < 0.5 s) and "poor" (RT > 0.5 s) room acoustics.

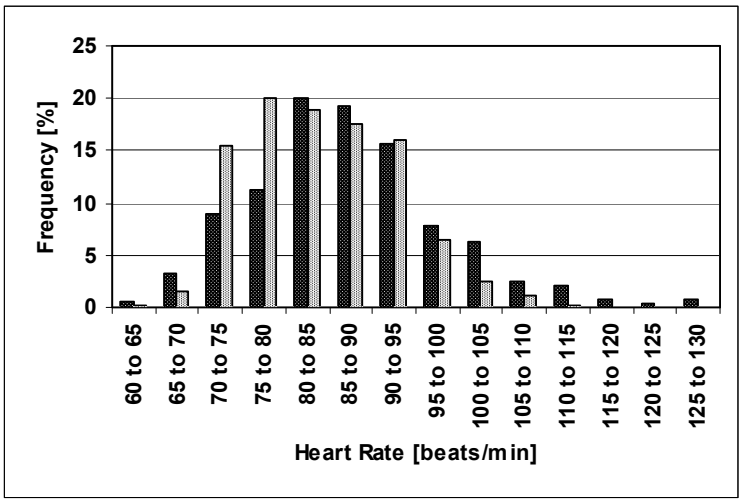


Fig. 5.116 Distribution of the average stress of all teachers when teaching, grouped according to classroom, RT < 0.5s (▒) and RT > 0.5s (▓); Grundschule Stichnathstraße

The frequency distribution of the HR under good room acoustics is approx. one class interval (5 beats/min) lower than under poor room acoustic conditions. The calculated median values are shown in Table 5.3 in which here again for an accurate comparison one would have to assume normal distribution of the values, which is not the case here.
The difference in both distributions for the teacher from the Baumberge Schule is considerably less dramatic. It is evident only in those shares of both classes next to the maximum (Fig. 5.117). Figures 5.118 and 5.119 show the corresponding distributions for the basic activity.

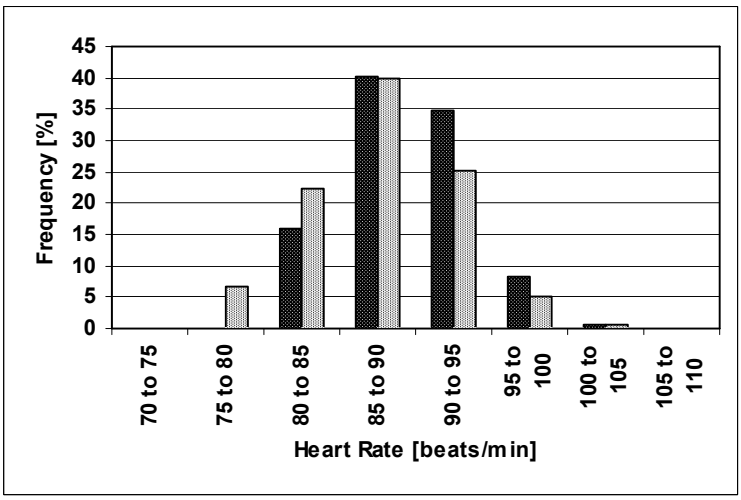


Fig. 5.117 Distribution of the average stress in teaching, grouped according to the conditions before (▓) and according to (▒) refurbishment; Baumberge Schule

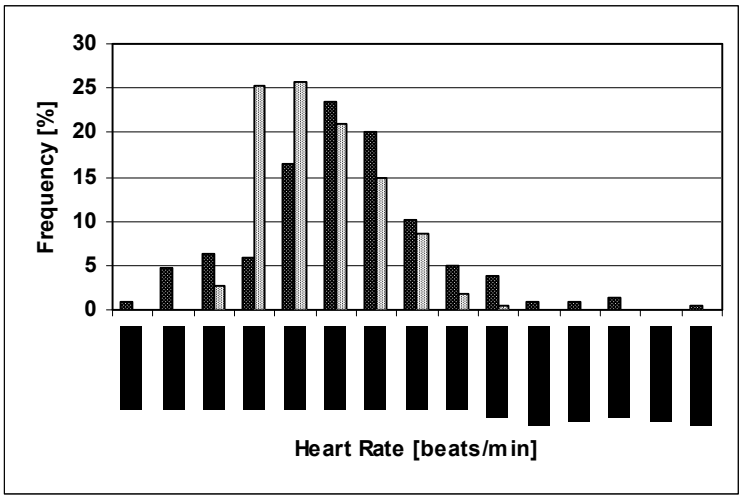


Fig. 5.118 Distribution of the basic activation in teaching for all teachers, grouped according to classroom, RT < 0.5s (▒) and RT > 0.5s (▓); Grundschule Stichnathstraße

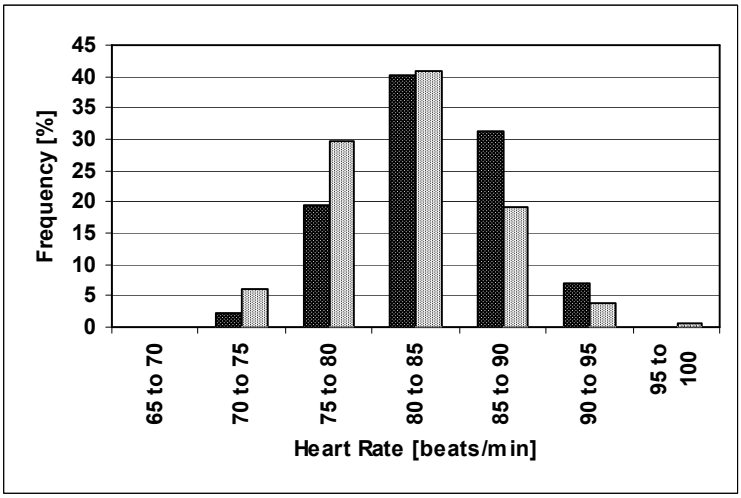


Fig. 5.119 Distribution of basic activation in teaching, grouped according to the conditions before (▓) and after the (▒) refurbishment; Baumberge Schule

While the distribution of the basic activation in the Baumberge Schule does not differ from the average stress, with respect to the change in conditions before/after the refurbishment, apart from the level, the difference in the group of teachers at the Grundschule Stichnathstraße is more distinct. In this case it is approx. 10 beats/min less under good room acoustic conditions.

None of the previous illustrations makes any difference with regard to the teaching day and the question about the possible advancement of fatigue, as can be observed in practically all work processes. The present analysis does not take into consideration the influence of the subject of the lesson or individual delayed starts to work because the lessons recorded, n = 156 for 12 persons, 5 teaching days and 5 lessons per day is too small.
Figure 5.120 shows the average stress levels during teaching at the Grundschule Stichnathstraße.

Table 5.3 Median values of stress and basic activation at the Grundschule Stichnathstraße (St) and Baumberge Schule (Bb)

	Median [1/min]			
Reverberation time	**Stress**		**Basic activation**	
School	**St**	**Bb**	**St**	**Bb**
RT > 0.5 s	84.7	88.5	76.0	83.0
RT < 0.5 s	83.7	87.9	74.0	82.0

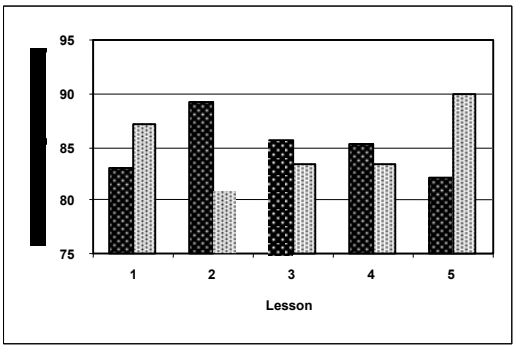


Fig. 5.120 Stress in teaching in the course of the teaching day, sorted according to ground floor (▓) and top floor (▒); Grundschule Stichnathstraße

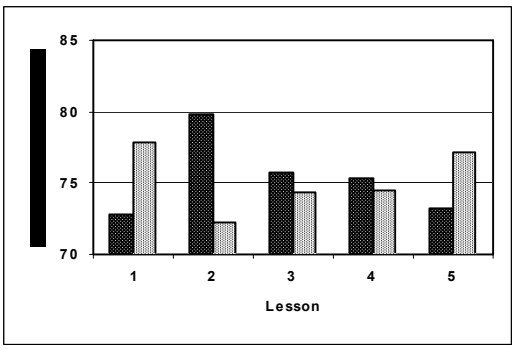


Fig. 5.121 Basic activation in teaching in the course of the teaching day, sorted according to ground floor (▓) and top floor (▒); Grundschule Stichnathstraße

At first glance the trend shown for the conditions on the ground5 floor and top floor of the school gives the impression, contrary to the general trend, of falling stress under poorer acoustic conditions, at least after the second lesson, with a corresponding increase in stress under better acoustic conditions. However, the lower overall stress in the second to fourth lessons (i.e. from the two peripheral lessons) is once again clearly shown. The question of fatigue is answered in the analysis of the basic activation, shown in Figure 5.121. The progression of the basic activation precisely corresponds to the stress in teaching, which means however that under poorer acoustic conditions (ground floor) from the 2nd lesson onwards, fatigue clearly sets in as compared to an increase in activation on the top floor.
The question about the actual progression of fatigue for one person under different room acoustic conditions can however only be illustrated by the example of the teacher from the Baumberge Schule, as shown in Figure 5.120.
This progression of stress would appear to indicate “constantly falling stress” before and after the refurbishment, i.e., the room acoustic refurbishment makes no difference with regard to the variation observed over the day. The difference between "good" and "poor" room acoustic situations found in the overall average values nevertheless appears again here.

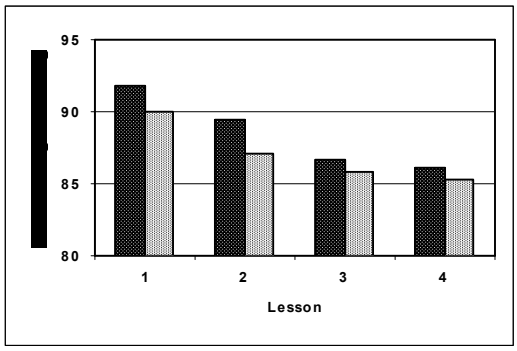


Fig. 5.122 Stress in teaching in the course of the teaching day before (▓) and after (▒) the refurbishment; Baumberge Schule

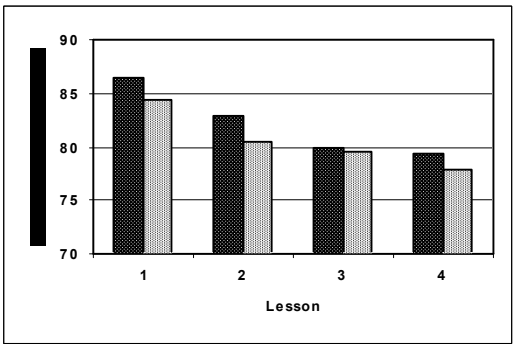


Fig. 5.123 Basic activation in teaching in the course of the teaching day, before (▓) and after (▒) the refurbishment; Baumberge Schule

The progressions of the basic levels of activation shown in Figure 5.123 reveal similar trends before and after the refurbishment, while somewhat greater before the refurbishment than after. If one compares the progressions of stress and the basic activation before and after the renovation one can see that the work effort, defined as

working pulse = stress – basic level of activity

is the same in both cases. After the refurbishment however it shifts to a consistently lower, i.e. more relaxed level. This is augmented by the considerably greater fall in the level of fatigue from the first to the fourth lesson before the refurbishment. The better acoustic conditions thus contribute to a reduced process of fatigue.
The question of fatigue processes cannot be answered fully on the basis of the present data material since this factor was not taken into consideration in the original project design. As previously shown, an increase in the heart rate indicates activity while a drop indicates fatigue.
The latter two figures, 5.122 and 5.123 illustrate a fatigue process over the morning. If one transfers this principle to 5 min. time slices, one can produce a very simplified representation of the trend of the heart rate broken down into:

Positive trend → activity
Negative trend → fatigue

Figure 5.124 shows a summary illustration of the HR-trend$_{5min}$ over all the observed time slices for all teachers at the Grundschule Stichnathstraße, broken down only according to the acoustic conditions of the classrooms. While under poorer acoustic conditions (ground floor) fatigue clearly predominates with 54 % (compared with 46 % share of activation), the ratio is more even under acoustic better conditions. The summation of all persons means that personal characteristics are lost.

The comparison for the teacher at the Baumberge Schule before and after the refurbishment gives a similar picture in terms of the trend, albeit at a different level. While the ratio of fatigue to activity was 58 % to 42 % before the room refurbishment, it is 56 % to 44 % after the refurbishment, i.e. a slight increase in activity and/or less fatigue (Fig. 5.125).

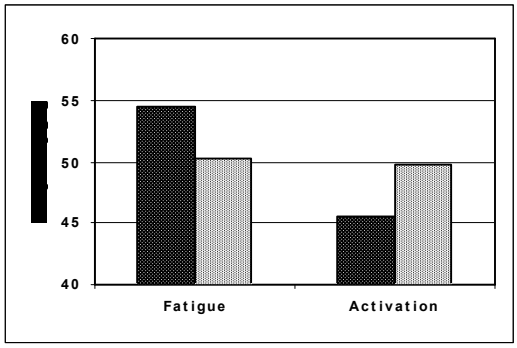


Fig. 5.124 Frequency distribution of positive and negative HR trends under different acoustic conditions, ground floor (▓) and top floor (▒); Grundschule Stichnathstraße

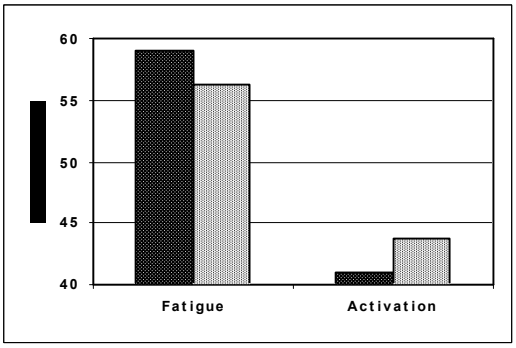


Fig. 5.125 Frequency distribution of positive and negative HR trends under different acoustic conditions, before (▓) and after (▒) refurbishment; Baumberge Schule

To analyse the question of fatigue in somewhat more detail the amplitude of the HR-trend$_{5min}$ is tested, i.e. shown in a frequency distribution. Figure 5.126 shows this for the Grundschule Stichnathstraße.

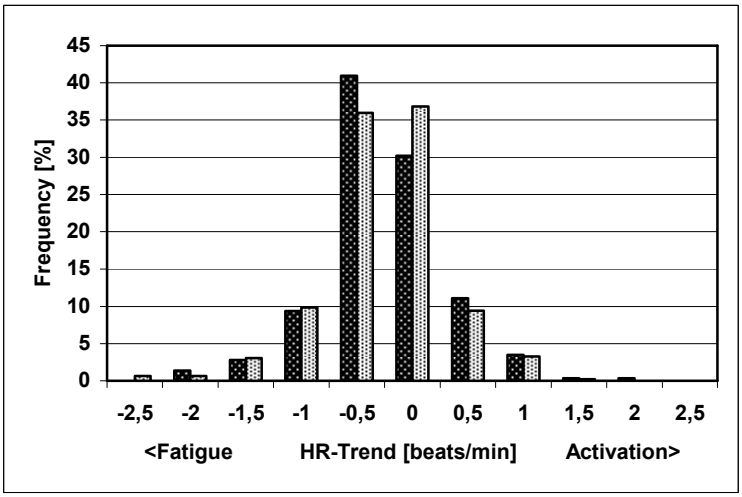


Fig. 5.126 Frequency distribution of the HR trend values for all teachers, grouped according to ground floor (▓) and top floor (▒); Grundschule Stichnathstraße

The difference between fatigue and activity found in the previous summary illustration is also reflected here. Since in the scaling of the classes the lower limits are shown in each case, this means that values between -0.5 and 0 are for the "-0.5" class and/or values between 0 and 0.5 are for the "0" class. For the ground floor we therefore find the maximum of the distribution in the fatigue range while there is a good balance between fatigue and activity for the top floor.
Figure 5.127 shows the corresponding distribution for the teacher at the Baumberge Schule before and after the refurbishment. As in the combined illustration the maximum distribution after the refurbishment in is the fatigue range but one can clearly see an increase in activity shares under the improved room acoustic conditions. Both illustrations include the fatigue over the school day.

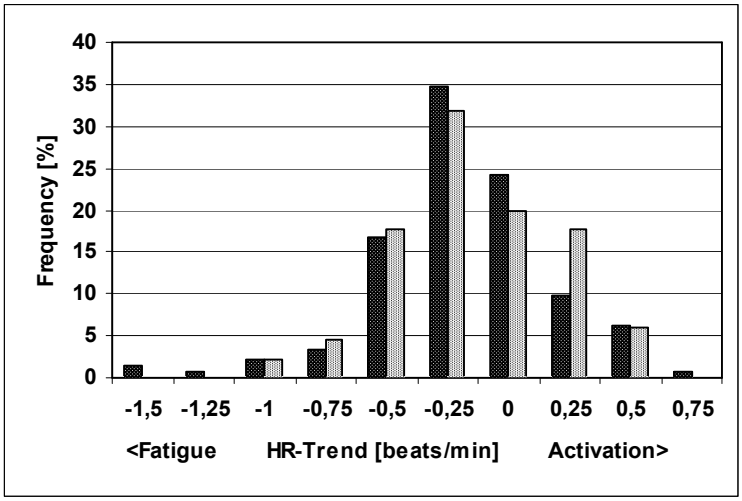


Fig. 5.127 Frequency distribution of the HR trend values over all lessons, grouped before (▓) and after (▒) refurbishment; Baumberge Schule

The breakdown of the data into lessons throughout the course of the day shows the following distribution of fatigue and activity for teachers teaching on the ground floor of the Grundschule Stichnathstraße (Fig. 5.128).

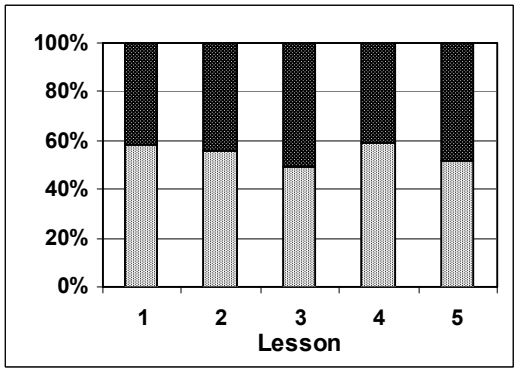


Fig. 5.128 Shares of fatigue (▒) and activity (▓) in the course of the day on the ground floor at the Schule Stichnathstraße (RT > 0.5)

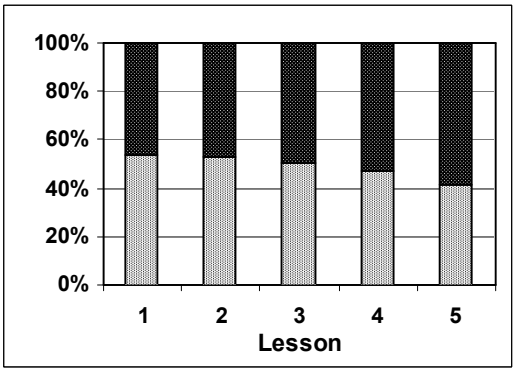


Fig. 5.129 Shares of fatigue (▒) and activity (▓) in the course of the day on the top floor at the Schule Stichnathstraße (RT < 0.5)

In this case fatigue predominates in 4 out of 5 lessons (except for the 3rd lesson) while a slight increase in the level of activation can be observed in the 5th lesson. However, the data from the top floor (Fig. 5.129) shows a clear increase in the levels of activity over the entire morning and activation shares actually predominate in the 4th and 5th lessons with values > 50 %.
A similar picture emerges for the individual teacher at the Baumberge Schule (Fig. 5.130). The overall higher percentage of fatigue, as already shown in the total, remains but the trend is similar to the group from the Grundschule Stichnathstraße. There is an evident trend towards a reduction of fatigue over the morning.

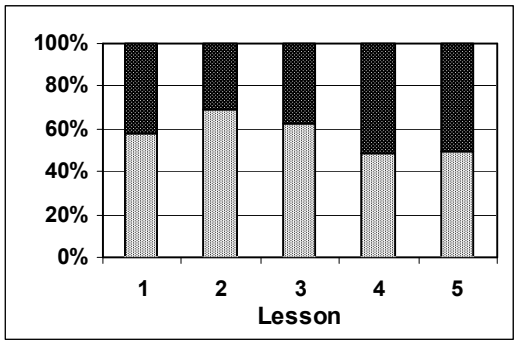


Fig. 5.130 Shares of fatigue (▒) and activation (▓) in the course of the day before the refurbishment (RT > 0.5s); Baumberge Schule

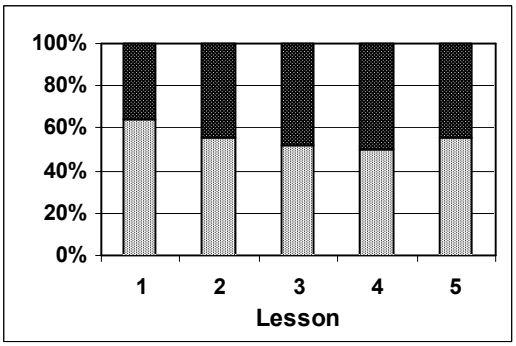


Fig. 5.131 Shares of fatigue (▒) and activation (▓) in the course of the day after the refurbishment (RT < 0.5s); Baumberge Schule

The dramatic increase of fatigue levels in the 2nd and 3rd lessons to over 60 % in the time before the refurbishment is very striking. Under the good room acoustic conditions after the refurbishment the distribution is very different (Fig. 5.131).
The increase in the proportion of activation found in the larger data record for the Grundschule Stichnathstraße over the morning in the rooms with good acoustic conditions is confirmed in the individual case.
The summary confirms a reduction of stress which can be determined at least on the part of the teachers under better room acoustic conditions. This relates both to the basic activation as well as to the absolute stress level. It is supplemented by a clear drop in fatigue processes which is associated with increase in activation. In terms of the workload-stress concept it is possible here to refer back to reduced stress and state that improving the acoustics of a room represents a reduction of the load.

5.2.2.2 Heart rate analysis in relation to the teaching method

Taking the workload-stress model of occupational science (see section 1.1) as a point of departure, the load of the human being comprises not only the ergonomic ambient conditions but also the task and/or activity and the associated requirements and activities as these are described in the “Transactional stress model” according to LAZARUS and LAUNIER.
With respect to teaching in schools this means redefining the specifications of education legislation and the curriculum as well as the practical execution of teaching as determined in detail by the teaching observation (see section 2). It is now worth asking whether (active?) direct teaching is more stressful than, for example, supervising student-centred activities.
Figure 5.132 gives an initial glance with a summary of the data for the teachers of the Grundschule Stichnathstraße – arranged according to teaching method and the respective shares of speech and grouped according to greater and smaller share.
With respect to the type of the teaching this initial composition reveals no discernible difference in stress. The working phases characterised by direct teaching appear to impose the same load on teaching staff as phases of student-centred teaching. There is a clear difference however in the difference in the shares of speech: When the teacher is talking more (greater share of teacher-generated speech) s/he is subject to considerably more stress than when s/he is talking less. Accordingly, the stress imposed by listening to a high share of student-generated speech is less. A

possible interpretation would be that listening causes less stress than speaking oneself.

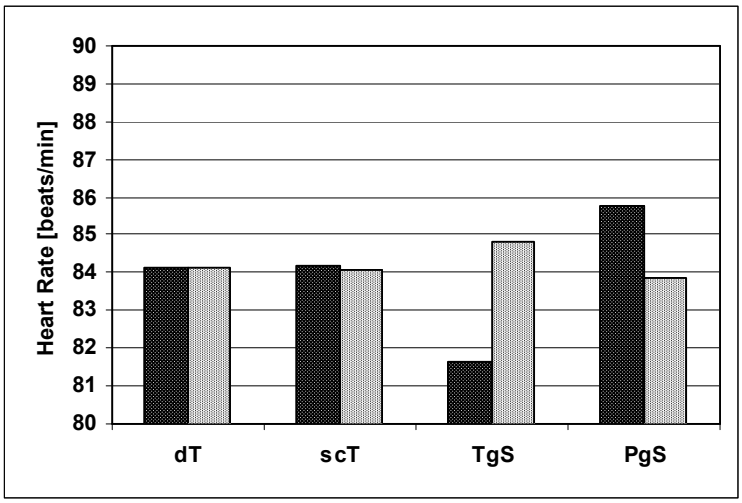


Fig. 5.132 Average stress in teaching, share of teaching method/speech, share < 50 % (▓), share > 50 % (▒), (N = 12 teachers); Schule Stichnathstraße

The same data analysis with respect to the teacher from the Baumberge Schule (Fig. 5.133) reveals more.

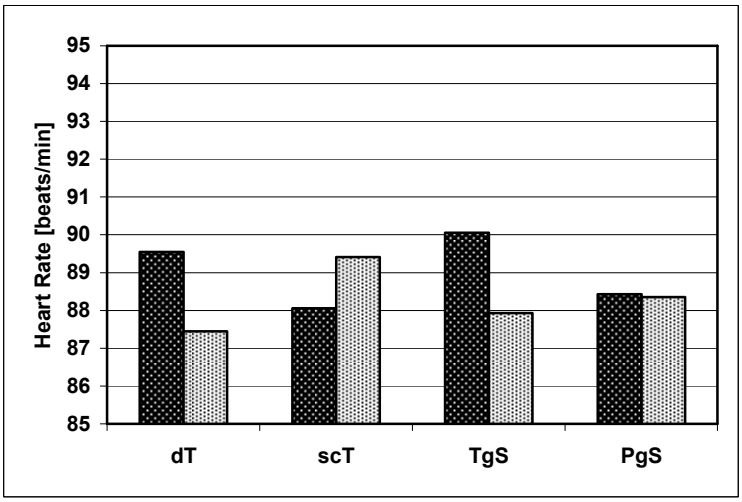


Fig. 5.133 Average stress in teaching, share of teaching method/speech, share < 50 % (▓), share > 50 % (▒), (N = 1 teacher); Baumberge Schule

As well as the individual change caused by the changes to the acoustic-ergonomic working conditions (before and after the refurbishment) the data basis also reveals the personal preference of this teacher for 'her' personal teaching style. For this teacher, an overwhelmingly direct teaching style causes far less stress than student-centred teaching methods. One can only speculate on the reasons for this. It is possible that the increased load is caused by the distribution of attention over several pupil groups rather than the unified approach of direct teaching. Direct teaching may however also mean greater control over the class and the resulting sense of security

may contribute to a sense of relaxation. This would match the findings regarding speech shares. The more the teacher speaks herself, the less her stress. Differentiating according to the pupil shares of speech does not however reveal any recognisable difference.
If one asks the same question not about average stress, but about the basic activation, the basic tension in other words, one gets a slightly different picture, particularly with regard to the teaching method. In the group of teachers from the Grundschule Stichnathstraße (Fig. 5.134) there now appears to be a difference between direct teaching and student-centred teaching methods: a greater share of direct teaching also generates a greater basic activation. This may reflect the fact that the tension involved in the synchronous teaching method is greater than directing smaller working units.

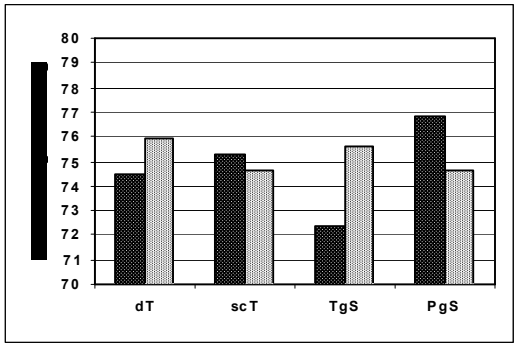


Fig. 5.134 Average basic activation in teaching, share of teaching method/speech, share < 50 % (▓), share > 50 % (▒), (n = 12 teachers); Grundschule Stichnathstraße

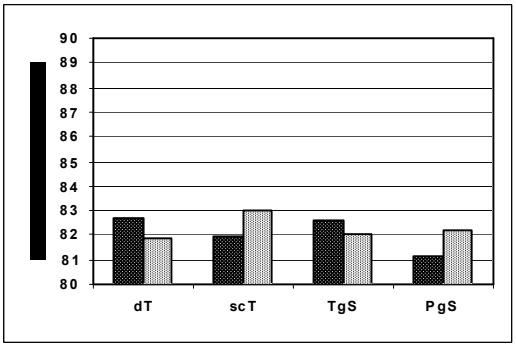


Fig. 5.135 Average basic activation in teaching, share of teaching method/speech, share < 50 % (▓), share > 50 % (▒), (n = 1 teacher); Baumberge Schule

This whole group presentation may nevertheless conceal different reactions from individual teachers. Therefore it is worth comparing the data for teacher from the Baumberge Schule (Fig. 5.135). The relation of the teacher's basic activation to her average stress levels for both teaching methods (Fig. 5.133) is very similar. The rise in the basic tension with a higher share of student-generated speech is worth noting however (and is possibly an explanation of the greater average stress in phases with less teacher-generated speech). The basic activation of the teacher, is definitively shown, albeit slightly influenced by the teaching method and deviations shift overall in an order of magnitude of maximum 1 beat per minute.
The reactions of the teacher in the Baumberge Schule to phases with different teaching methods and/or shares of speech of teachers and pupils appear to almost exactly contradict those of her colleagues at the Grundschule Stichnathstraße. Whether this is due however to the personal constitution of the teacher, to the different pedagogical styles of the schools (along with a certain response pattern amongst teachers at Stichnathstraße) cannot be clarified on the basis of this data. It would need a more comprehensive comparative study with a different design.
Average values for the measured stress must of course be considered as being merely orientational in nature. To answer the key questions requires closer analysis. Therefore the HR data is now analysed as to its distribution, related respectively to the teaching method and or shares of speech. As above, the data for the teacher from the Baumberge Schule and the aggregate of the data of the 12 teachers of the Grundschule Stichnathstraße is handled separately in this step.

This analytical step shows something which was not revealed by the summary of average values. The distribution of stress in teaching (Fig. 5.136) shows a slight but measurable shift in the distribution towards lower values in phases with a greater share of direct teaching. In fact therefore the teacher in the Baumberge Schule is not out of character (Fig. 5.137. We can see once again Fig. 5.133) that a greater share of direct teaching (> 50 %) evidently produces somewhat less stress than other teaching methods amongst teaching staff in the Grundschule Stichnathstraße. Interpretations, see above.

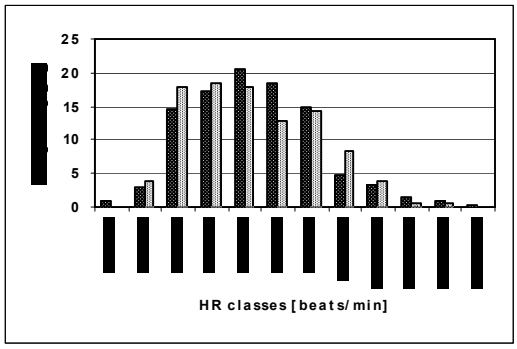


Fig. 5.136 Frequency distribution of the average-HR_{5min}, sorted according to phases with a higher or lower share of dT, share < 50 % (▓), share > 50 % (▒), (n = 12 teachers); Grundschule Stichnathstraße

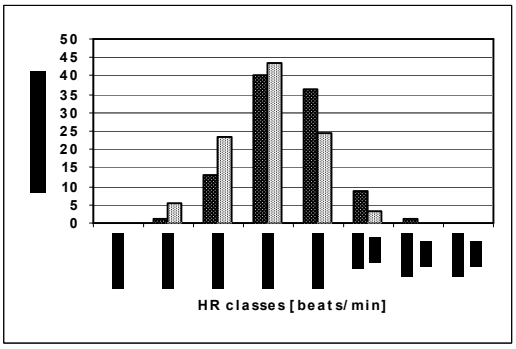


Fig. 5.137 Frequency distribution of the average-HR_{5min}, sorted according to phases with a higher or lower share of dT, share < 50 % (▓), share > 50 % (▒), (n = 1 teacher); Baumberge Schule

Based on these observations, stress in phases involving other than direct teaching must be correspondingly higher. In fact the relationship with student-centred teaching methods in Figures 5.138 and 5.139 can be determined for the Grundschule Stichnathstraße as well as for the Baumberge Schule.

Particularly in the data record from the Grundschule Stichnathstraße the difference between the stress caused by student-centred teaching methods (> 50 %) and non-student-centred teaching methods (< 50 %) is strikingly evident (Fig. 5.138). The shift is by at least an entire class interval, i.e. over 5 beats per minute. This means that the repeated promoted "modern" teaching methods – partner work, group work or project work – place an objectively greater measurable physiological load on teachers than traditional direct teaching.
Astoundingly, the individual analysis from the Baumberge Schule revealed this difference to a lesser extent but reflected the trend identically (Fig. 5.139). The fact that the difference is less for this school and/or this person however might be because the share of scT time overall is so low. It is nevertheless evident that teacher stress is considerably higher in phases with a high share of scT time > 50 % than in other phases. It requires more attentiveness, particularly divided attentiveness, from the teachers than direct teaching.

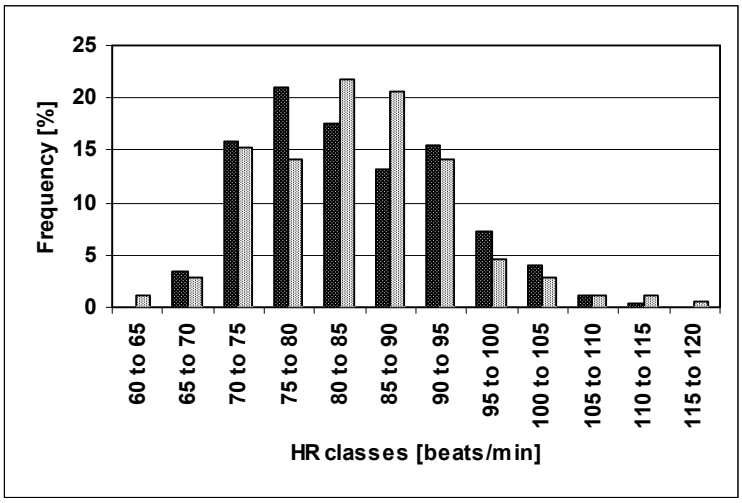


Fig. 5.138 Frequency distribution of the average-HR_{5min}, sorted according to phases with a higher or lower share of scT, share < 50 % (▓), share > 50 % (▒), (n = 12 teachers); Schule Stichnathstraße

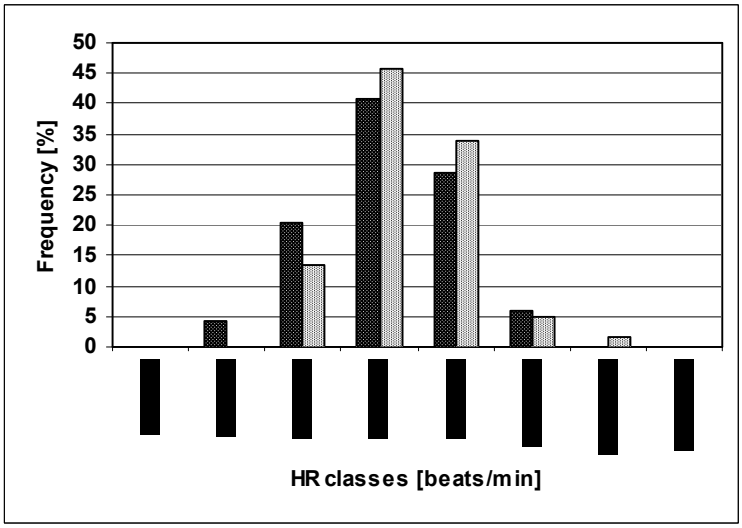


Fig. 5.139 Frequency distribution of the average-HR_{5min}, sorted according to phases with a higher or lower share of scT, share < 50 % (▓), share > 50 % (▒), (n = 1 teacher); Baumberge Schule

In a next step the question remains as to whether these differences with regard to stress are also reflected in the basic tension of the teaching staff, measured as the basic activation. This relates nothing less than to the question as to what basic behaviour the teacher adopts for a particular teaching method. Figures 5.140 and 5.141 show the frequency distribution of the basic activation in phases with lower (< 50 %) and higher (> 50 %) shares of student-centred teaching for all teachers at the Grundschule Stichnathstraße and for the teacher at the Baumberge Schule. In fact practically the same distribution is obtained for the basic activation in both schools as for the average stress.

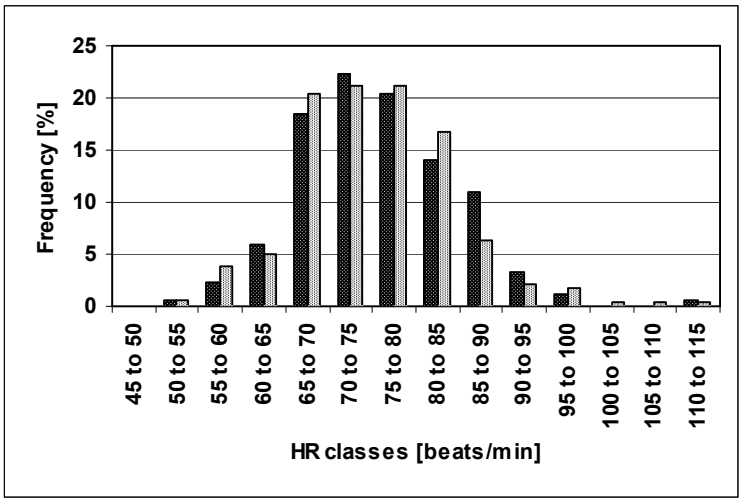


Fig. 5.140 Frequency distribution of the basic activation HR_{5min}, sorted according to phases with a higher or lower share of scT, share < 50 % (▓), share > 50 % (▒), (n = 12 teachers); Grundschule Stichnathstraße

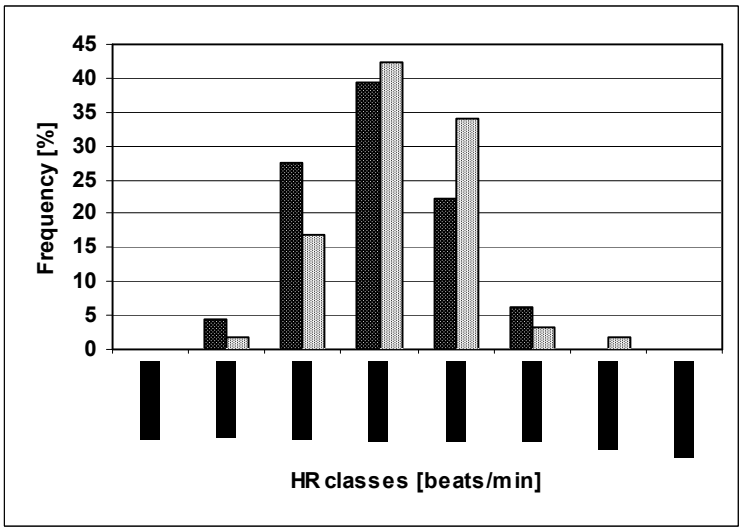


Fig. 5.141 Frequency distribution of the basic activation HR_{5min}, sorted according to phases with a higher or lower shares of scT, share < 50 % (▓), share > 50 % (▒), (n = 1 teacher); Baumberge Schule

The analysis of the individual data from the Baumberge Schule (Fig. 5.141) once again clearly shows how much more relaxed the teacher is during non student-centred teaching phases. The shift in frequencies is shown most clearly here. As shown earlier, the phases with direct teaching also occupy the far greater share of teaching time. A possible interpretation might well be that direct teaching is the most familiar teaching method and therefore represents less of a load. It is not possible to take into consideration another possible influential factor, that of the load produced by motor activity, i.e. standing for direct teaching and walking towards the working groups. This was not monitored.

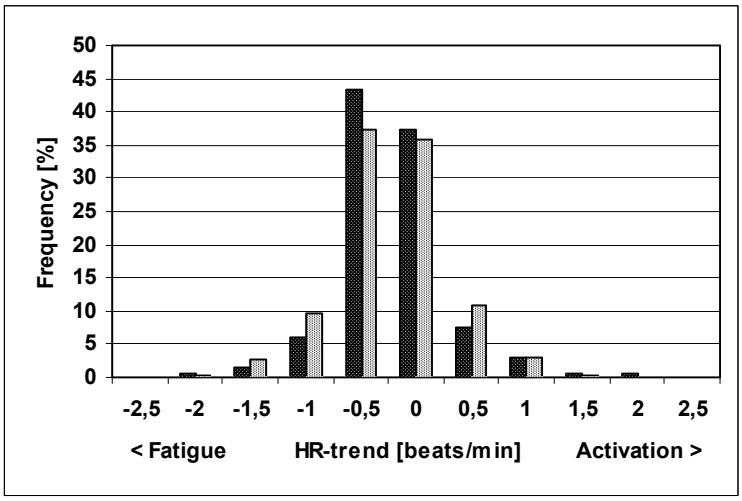


Fig. 5.142 Frequency distribution of the HR-trend$_{5min}$, sorted according to phases with a predominant share of dT (▓) and/or scT (▒), Schule Stichnathstraße n = 12

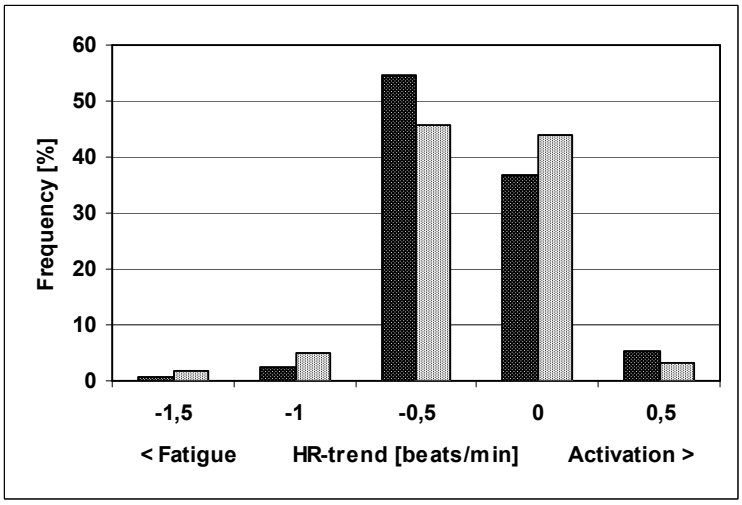


Fig. 5.143 Frequency distribution of the HR-trend$_{5min}$, sorted according to phases with a predominant share of dT (▓) and/or scT (▒), Baumberge Schule n = 1

The central question is ultimately about the impact of different teaching methods on fatigue and/or activation of the teacher. The distribution of the HR-trend$_{5min}$ provides information in this respect. In Figure 5.142 the data – again sorted according to phases with a predominant share of direct teaching and student-centred teaching methods – is shown again for all teachers of the Grundschule Stichnathstraße while Figure 5.143 shows the data for the teacher at the Baumberge Schule.
It is possible to determine a slight trend towards greater fatigue in both schools and particularly clearly in the Baumberge Schule in those phases with a predominant share of direct teaching. Overall, however, the shares of fatigue and activation are surprisingly similar particularly in the Grundschule Stichnathstraße. This means, albeit on average amongst all teaching staff, that neither of the two teaching methods contributes significantly more to fatigue or activation than the other.

It can be therefore be established that student-centred teaching methods lead to greater stress than direct teaching methods and that this is partly due to the dividing of attention. More working groups need to be monitored simultaneously and possibly supported in turn. With direct teaching the group to be monitored is bigger, i.e. the whole class. However, full attention is only required for one group.

5.2.2.3 Heart rate analysis in relation to shares of speech

After filtering by teaching method we now turn to the question of whether the stress of teaching staff can be related in principle to specific communication features.

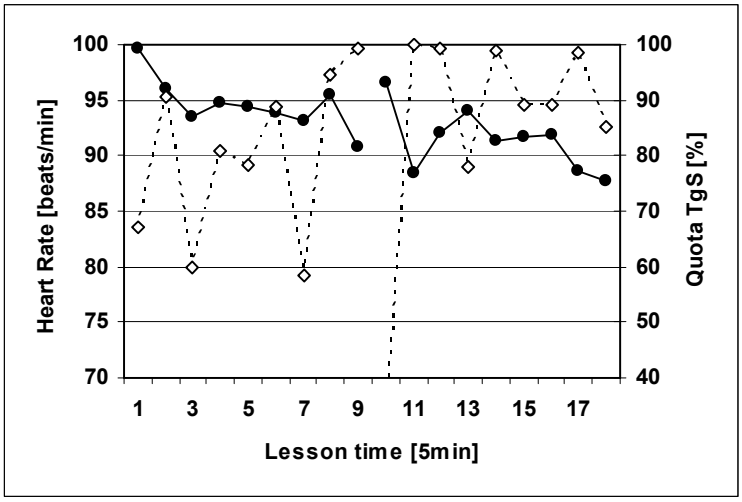


Fig. 5.144 Progression of the share of TgS (◊) and average stress (●) over two lessons. (Example from the Baumberge Schule)

It is time to ask what type of communication – irrespective of its content – causes greater stress for teachers and which causes less? As an initial approach to the question, Figure 5.144 shows the synchronous progression of the shares of speech of a teacher and his/her average stress based on the example of the first and second lessons of the school day.

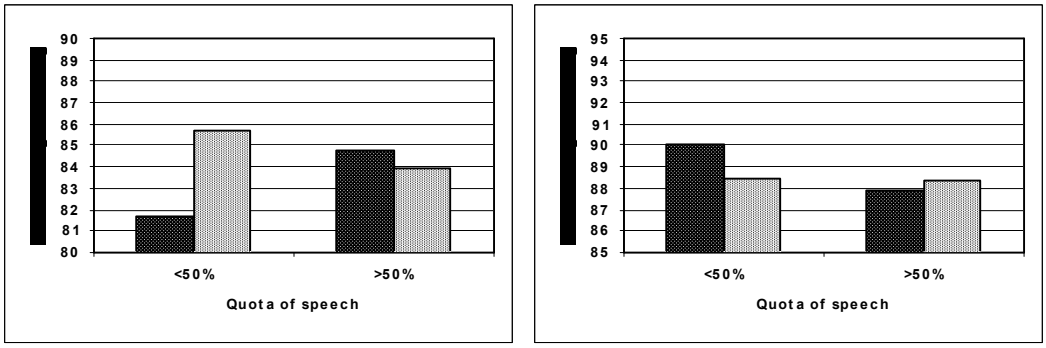


Fig. 5.145 Average stress in teaching depending on the shares of speech of teachers (▓) and pupils (▒), left Schule Stichnathstraße (n = 12), right Baumberge Schule (n = 1)

There now follows a more detailed examination of the significance of the shares of speech in teaching for the stress of the teacher. Figure 5.145 shows the average

stress for teachers in both schools for the phases with low (< 50 %) and high (> 50 %) shares of speech.

As one might expect, the stress for the teachers of the Grundschule Stichnathstraße in phases with a high proportion of teacher-generated speech (TgS) is greater than in phases with a low proportion of teacher-generated speech. If, however, we consider this in relation to the phases with low and/or high shares of student-generated speech (SgS) a corresponding picture emerges but on a much higher level, i.e. in phases with a low proportion of SgS, stress levels are even higher than in phases with a high proportion of TgS. These are obviously phases in which a greater load is imposed on the teacher. In this context it is once again important to mention that the phases with little TgS are in no way identical to the phases with a high proportion of SgS or the reverse!
Once again a different picture is given by the data for the individual teacher at the Baumberge Schule than for the staff as a whole at the Stichnathstraße (Fig. 5.145 right). While stress levels in this case, at least based on the average values, are largely irrespective of the share of SgS they do rise considerably when the teacher herself is talking little. She is least stressed, on the other hand, in those phases in which her speech dominates (and thus has control over the events?). This corresponds to the previous statements made about the stress of this teacher as related to the difference between direct teaching and student-centred teaching methods.
If one considers this effect based on the distribution of the average stress (Fig. 5.146) the picture becomes somewhat clearer. The visible shifts to the left and/or right verify the higher stress experienced during the high share of TgS in the Schule Stichnathstraße and during the low share of TgS in the Baumberge Schule.
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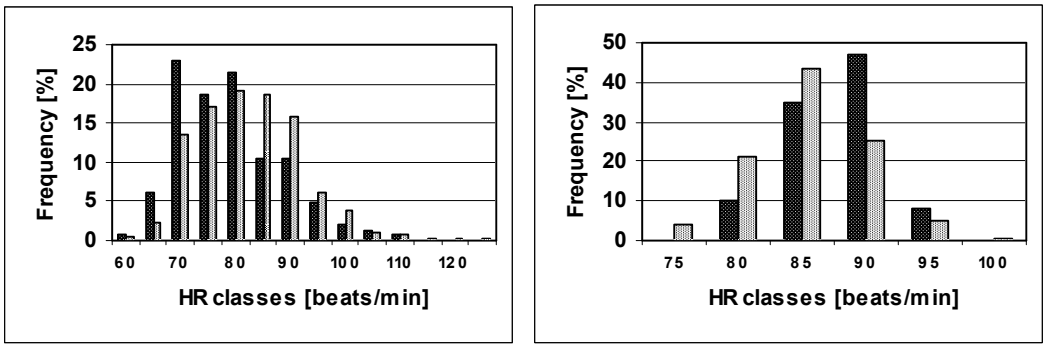

Fig. 5.146 Frequency distribution of the average stress in teaching depending on the teacher speech shares, share < 50 % (▓) and > 50 % (▒), left Schule Stichnathstraße (n = 12), right Baumberge Schule (n = 1)

In relation to the shares of speech of the pupils a surprising picture emerges of the frequency distribution (Fig. 5.147) compared with the average values (see Fig. 5.145). The relationship between stress and student-generated speech that is implied by the values obtained for the Grundschule Stichnathstraße is not confirmed by the frequency distribution. In fact in both schools this is not definitively influenced by the student-generated speech so one might assume, unlike the first trends, that attentiveness as a factor of the stress is largely independent on the shares of speech of the pupils.

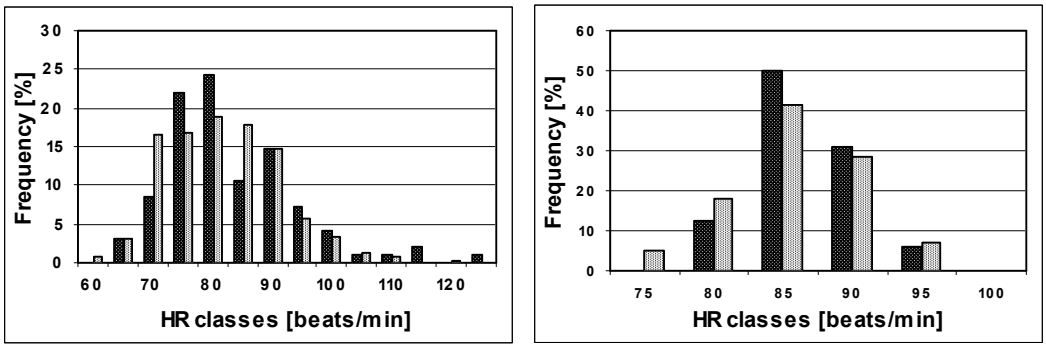

Fig. 5.147 Frequency distribution of the average stress in teaching depending on the shares of speech of the pupils, share < 50 % (▓) and > 50 % (▒), left Schule Stichnathstraße (n = 12), right Baumberge Schule (n = 1)

With regard to the basic activation an initial glance at the average values (Fig. 5.148) indicates similar results to those for the average stress in teaching. This in turn indicates that the respective activity stimulates the basic activation.

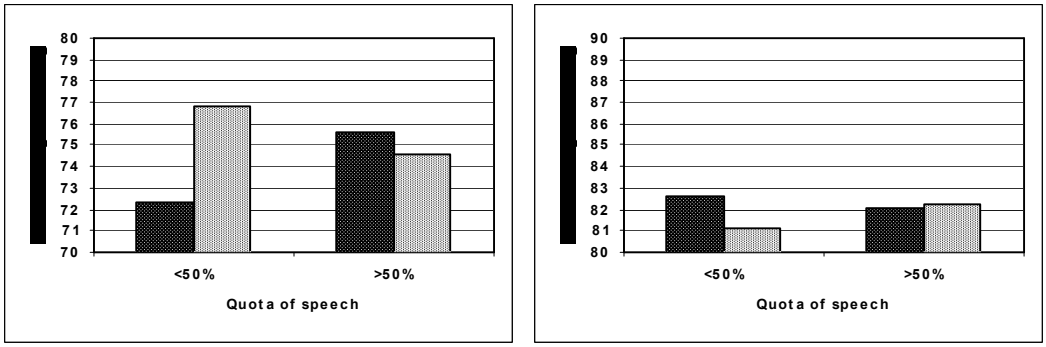

Fig. 5.148 Average stress in teaching depending on the teacher speech shares (▓) and pupils (▒), left Schule Stichnathstraße (n = 12), right Baumberge Schule (n = 1)

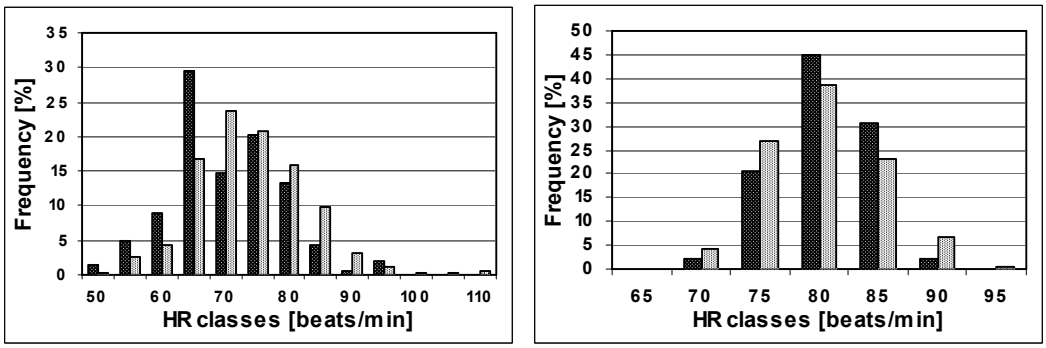

Fig. 5.149 Frequency distribution of the average stress in teaching depending on the teacher speech shares, share < 50 % (▓) and > 50 % (▒), left Schule Stichnathstraße (n = 12), right Baumberge Schule (n = 1)

For the sake of confirmation at this point it is worth looking again at the distribution of the basic activation for both schools, as shown in Figure 5.149. It largely corresponds to the distribution of the average stress in Figure 5.146. The distribution of the basic

activation also appears to have no relation to the share of student-generated speech SgS (no fig.).
If therefore a specific activity has a clear influence on the basic activation one needs to ask again the question about fatigue and/or activation. The trend measurement for the respective speech phases is shown for both the schools in Figures 5.150 and 5.151. In this case for the teachers at the Grundschule Stichnathstraße there is a slight predominance of activation shares in phases with less TgS on average, while activation and fatigue weigh more heavily in phases with higher shares of TgS, (Fig. 5.150, left). At the Baumberge Schule, however, fatigue predominates for the teacher in both cases and considerably more in phases of low TgS, 63 % to 37 % than for higher shares, 55 % to 45 % (Fig. 5.150, right).

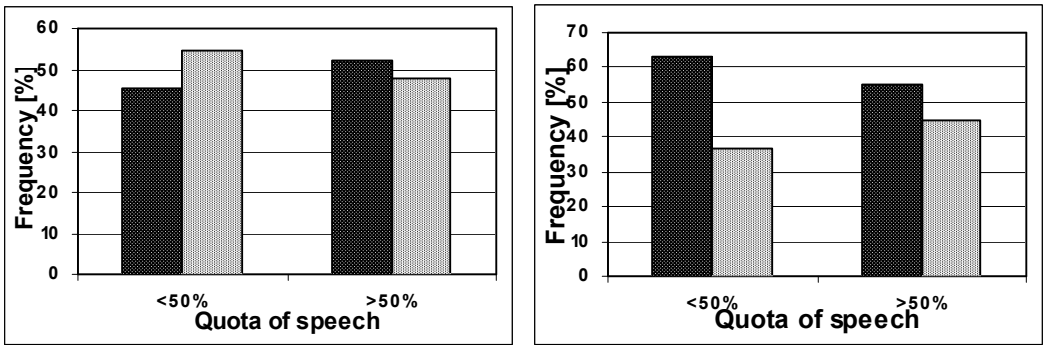

Fig. 5.150 Frequency of fatigue (▓) and activation (▒) in teaching depending on the share of TgS, left Schule Stichnathstraße (n = 12), right Baumberge Schule (n = 1)

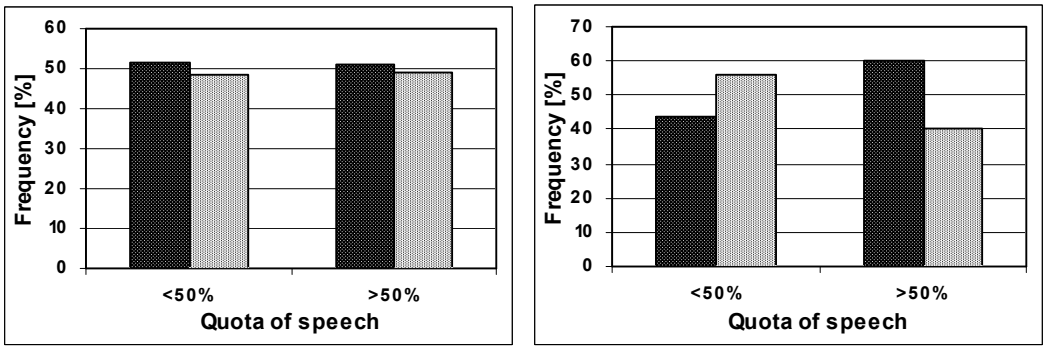

Fig. 5.151 Frequency of fatigue (▓) and activation (▒) in teaching depending on the share of SgS, left Schule Stichnathstraße (n = 12), right Baumberge Schule (n=1)

There is no discernible difference with respect to the shares of speech of the pupil for the teachers at the Grundschule Stichnathstraße. Fatigue and activation are the same in both cases (Fig. 5.151, left). For the interpretation, however, it is necessary to mention once again that phases with high shares of teacher-generated speech are not the same as shares of low SgS. There are overlaps because the two shares were recorded in parallel rather sequentially. As expected by now, one can see the opposite for the teacher at the Baumberge Schule, i.e. greater fatigue during high shares of SgS and greater activation during low shares of SgS (Fig. 5.151, right).
Overall it is possible to discern here the influence of her own share of speech on her stress level, which to a great extent is certainly due to an increased basic activation

at the corresponding moment. The "opposite example" of the teacher from the Baumberge Schule for the average trend teaches us however that the preferred teaching method of the respective teacher and the associated activity also plays a large part. The question as to the extent to which stress is generated by speaking or listening remains academic. It is impossible to investigate in this kind of non-manipulated field study and would require laboratory conditions. In this case, however, the extent to which these could mirror the reality of teaching would remain open to question.

5.2.2.4 Analysis of the heart rate in relation to selected filter combinations

The stress of teachers in teaching, as also defined in the workload-stress concept, depends above all on factors determining the work system. The previous sections enabled relationships between the different strengths of the effects of room acoustics, teaching methods and shares of speech of teacher and pupils to be shown. The aim of this section is to show the mutual influences of the parameters as far as this can be determined. The complexity of such a data record is shown in the extract in Figure 5.152 which shows two synchronously recorded parameters, the heart rate as an indicator of stress and the shares of teacher-generated speech over the period. If one overlays the two records of the same weekday, once before the room refurbishment (RT > 0.5 s) and once after the refurbishment (RT < 0.5 s), one can see the effect of the room acoustics. This figure may be defined as:

Stress = function of (time, teacher-generated speech, room acoustics)

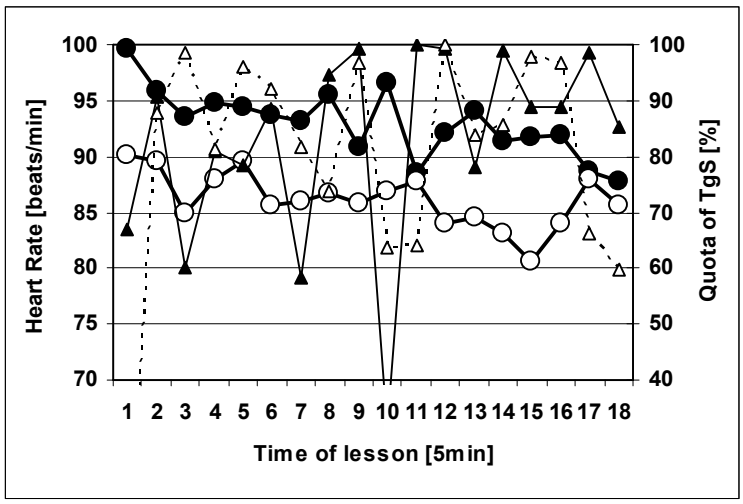

Fig. 5.152 Baumberge Schule, synchronous illustration of average-HR (●○) and TgS (▲Δ) for RT > 0.5s (●▲) and RT < 0.5s (○Δ)

However, it is not possible to make an overall and therefore conclusive analysis based on individual trends during the lessons. Taking other parameters into consideration, this requires an averaging of time slices of lessons. This has already been carried out in the preceding sections based on teaching method and shares of speech. One now needs to determine the average stress as a result of direct teaching, taking a room's acoustic conditions into account. For this purpose the next section examines the average stress and the share of direct teaching calculated for

each lesson and differentiated according to RT > 0.5 s and RT < 0.5 s, i.e. poorer and/or better room acoustics. Figure 5.153 shows the data for the Grundschule Stichnathstraße.

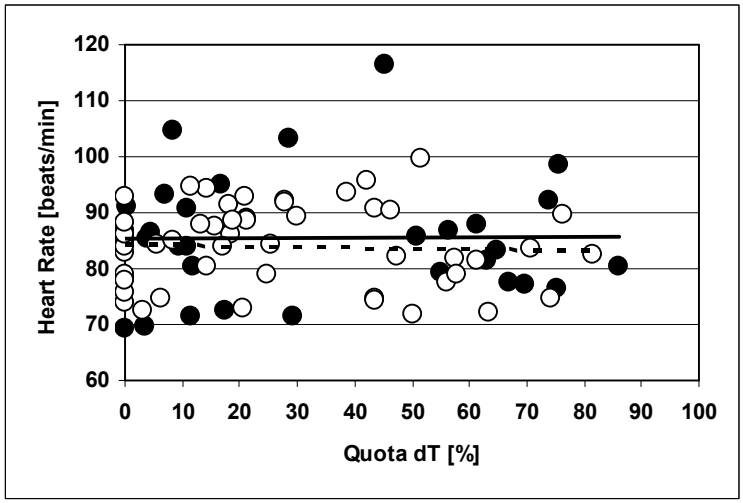

Fig. 5.153 Stress in teaching in relation to the share of dT time; Classrooms with RT > 0.5s on the ground floor (●) and RT < 0.5s on the top floor (○), regression line, ground floor (▬) and top floor (- -), (n = 12 teachers); Grundschule Stichnathstraße

At the same time the linear regression was calculated for both groups as follows:

$$Y = A + B * X$$

	N	*A*	*B*	*r*
RT > 0.5	*32*	*85.26*	*0.01*	*0.02*
RT < 0.5	*51*	*84.37*	*-0.01*	*0.04*

The two regression rates reveal no significant difference for the staff of the Grundschule Stichnathstraße. The single striking feature is a slight difference in the trend of the increase. An increased share of dT therefore caused less stress for teachers in the rooms with better acoustics than in those with poorer acoustics. One is once again reminded of the limitations indicated by the problem of different groups of people. The immediate impact of the room acoustics on stress can be more accurately determined on the basis of the teacher from the Baumberge Schule (Fig. 5.154):
The regression coefficients for this teacher show a much clearer dependency. The very different rate of increase is particularly striking. After the acoustic refurbishment stress falls considerably as the share of dT rises. Teaching using this teaching method under good acoustic conditions – at least for this teacher – imposes a considerably lesser load. However, what does the basic activation for the teachers reveal? Once again attention is turned to determining the basic tension present in the different lessons. Initially the regression rates are determined for the data from the Grundschule Stichnathstraße (Fig. 5.155).

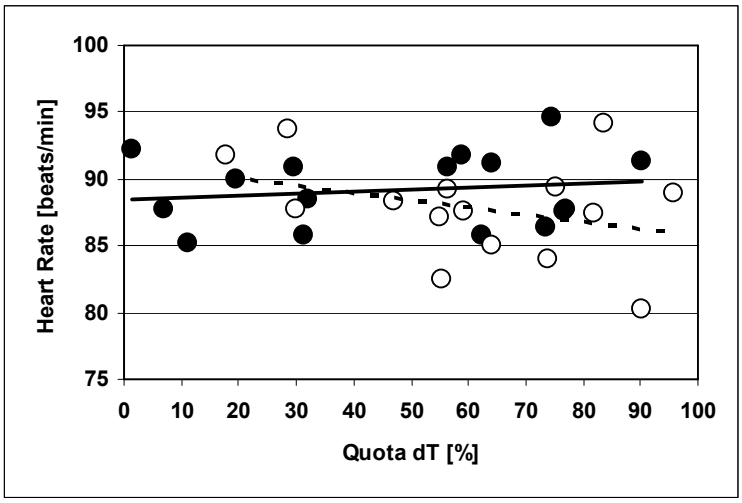

Fig. 5.154 Stress in teaching in relation to the share of dT time before (●) and after the refurbishment (○), regression line before (▬) and after (- -) the refurbishment, (n = 1 teacher); Baumberge Schule

Y = A + B * X

	N	***A***	***B***	***r***
RT > 0.5	*16*	*88.50*	*0.01*	*0.16*
RT < 0.5	*15*	*91.16*	*-0.06*	*0.34*

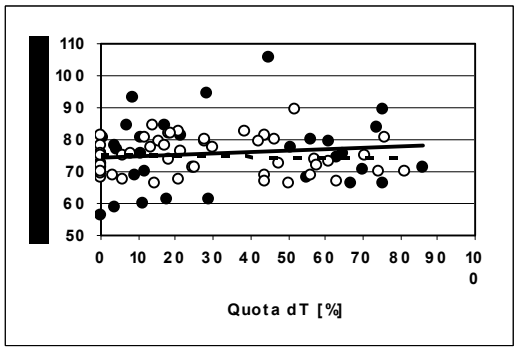

Fig. 5.155 Basic activation in teaching in relation to the share of dT time; classrooms with RT > 0.5s on the ground floor (●) and RT < 0.5s on the top floor (○), regression line, ground floor (▬) and top floor (- -), (n = 12 teachers); Grundschule Stichnathstraße

*Y = A + B*X*

	N	*A*	*B*	*r*
RT > 0.5	*32*	*74.29*	*0.04*	*0.11*
RT < 0.5	*51*	*74.93*	*-0.01*	*0.03*

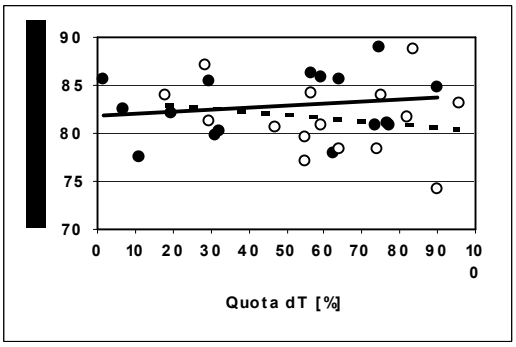

Fig. 5.156 Basic activation in teaching in relation to the share of dT time; before (●) and after the refurbishment (○), regression line before (▬) and according to (- -) the refurbishment, (n = 1 teacher); Baumberge Schule

*Y = A + B*X*

	N	*A*	*B*	*r*
RT > 0.5	*16*	*81.80*	*0.02*	*0.19*
RT < 0.5	*15*	*83.52*	*-0.03*	*0.20*

As in the case of the data for the average stress there is no evidence here of a significant relationship. However, the effect tends to confirm that under good acoustic conditions and an increased share dT the measured basic activation was somewhat lower. For the teacher at the Baumberge Schule an equivalent picture is given with regard to her average stress level (Fig. 5.156).

The adaptation of the regression rates is again somewhat clearer here than in the Grundschule Stichnathstraße but still largely insignificant. However, it shows again that basic tension reduces as the share of dT increases under better acoustic conditions.
How does the heart rate of the teaching staff behave under different basic acoustic conditions with regard to student-centred working phases? The preceding analysis, illustrated in section 5.2.2.2, showed no clear relationship between stress and the teaching method. If one assumes that the student-centred teaching method however will mean more noise than the combined results of direct teaching, the room acoustics may have a greater impact in this case. Figure 5.157 shows this relationship for the teachers at the Grundschule Stichnathstraße. The regression rates show a slight increase in stress for both situations as the share of student-centred teaching increases. In fact this increase is somewhat less under better acoustic conditions (RT < 0.5 s). The stress of the teachers at the Grundschule Stichnathstraße during student-centred teaching phases is positively influenced by the room's acoustic working environment (albeit with weak regression coefficients).

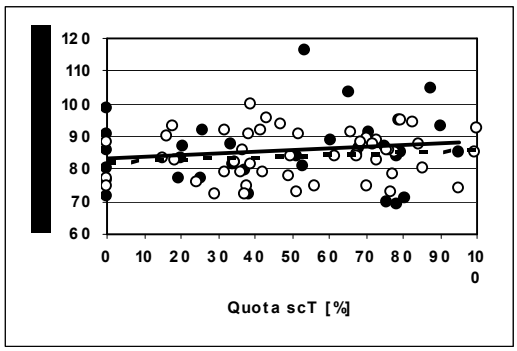

Fig. 5.157 Stress in teaching in relation to the share of scT time; classrooms with RT > 0.5s on the ground floor (●) and RT < 0.5s on the top floor (○), regression line, ground floor (▬) and top floor (- -), (n = 12 teachers); Grundschule Stichnathstraße

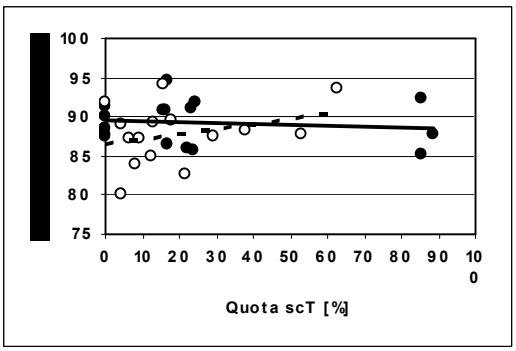

Fig. 5.158 Stress in teaching in relation to the share of scT time; before (●) and after the refurbishment (○), regression line before (▬) and according to (- -) the refurbishment, (n = 1 teacher); Baumberge Schule

*Y = A + B*X*

	N	*A*	*B*	*r*
RT > 0.5	*32*	*83.09*	*0.05*	*0.15*
RT < 0.5	*51*	*82.26*	*0.03*	*0.12*

*Y = A + B*X*

	N	*A*	*B*	*r*
RT > 0.5	*16*	*89.53*	*-0.01*	*0.14*
RT < 0.5	*15*	*86.53*	*0.06*	*0.31*

The opposite picture emerges however for the teacher at the Baumberge Schule. Her stress rises considerably under good acoustic conditions as the share of student-centred teaching increases (Fig. 5.158). In fact the regression line before the

refurbishment is definitively affected by three rather atypical lessons for this teacher. If one were to leave this out of consideration one would see a similar picture as for the staff at the Grundschule Stichnathstraße. It is therefore worth interpreting this "result" with due caution. The observation of the basic activation relating to student-centred teaching shows largely the same picture in relation to average stress as that shown for direct teaching in both schools (no fig.). Against this background there remains the question of the indirect impact of the teacher's own speech process on the stress level. Do similar shares of teacher-generated speech cause different stress levels under different room acoustic conditions / communication conditions?
In this context it is worth mentioning again that this fact can only be tested between the two groups for the teachers at the Schule Stichnathstraße. The impact on individuals cannot be determined on the basis of this data record. Figure 5.159 however shows unexpectedly clearly a greater increase in stress under the poorer acoustic conditions on the ground floor as the share of speech increases than under the better acoustic conditions on the top floor. In this case a closer relationship with the better speech intelligibility in the classrooms RT < 0.5 s may be safely assumed. The result verifies that speech in these rooms is less strenuous.

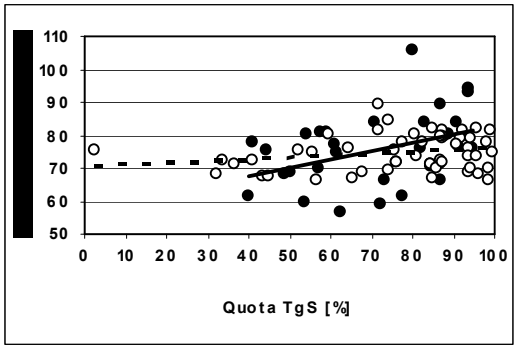

Fig. 5.159 Stress in teaching in relation to the share of TgS time; classrooms with RT > 0.5s on the ground floor (●) and RT < 0.5s on the top floor (○), regression line, ground floor (▬) and top floor (- -), (n = 12 teachers); Grundschule Stichnathstraße

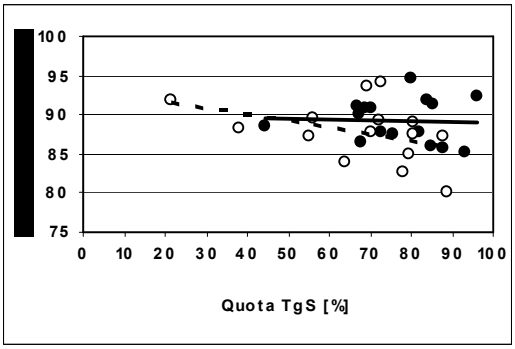

Fig. 5.160 Stress in teaching in relation to the share of TgS time; before (●) and after the refurbishment (○), regression line before (▬) and according to (- -) the refurbishment, (n = 1 teacher); Baumberge Schule

*Y = A + B*X*

	N	*A*	*B*	*r*
RT > 0.5	*32*	*69.48*	*0.24*	*0.38*
RT < 0.5	*51*	*75.96*	*0.11*	*0.32*

*Y = A + B*X*

	N	*A*	*B*	*r*
RT > 0.5	*16*	*89.84*	*-0.01*	*0.04*
RT < 0.5	*15*	*93.34*	*-0.08*	*0.40*

Even if the results of the regression calculation are not significant, there is still a clearer relationship here than with the teaching method. More so when one observes the impact of the acoustic refurbishment of the room on the personal stress level of the teacher at the Baumberge Schule, who differs due to her preference for direct teaching from the habits of the teachers at the Grundschule Stichnathstraße (Fig. 5.160). While under the original acoustic working conditions (RT > 0.5 s) the proportion of the teacher's own speech has no impact on stress, the regression rate

data clearly shows that stress falls after the refurbishment as the share of the teacher's own speech increases.
According to the overall view of the average lesson values the next section looks more closely at stress depending on the room acoustics within the working phases with high proportions of direct and/or student-centred teaching methods. The relationships in this analysis process are more easily obtained than those relating to lesson-based values. Thus a glance at the distribution of the average basic activation in predominantly direct teaching periods for the Grundschule Stichnathstraße (Fig. 5.161) reveals a shift by some 5 [beats/min] under more favourable acoustic conditions, i.e. more relaxed. Using the same teaching method (dT) the teachers on the top floor (RT < 0.5 s) are therefore working with a lower basic activation and are therefore more relaxed. The same picture emerges for the teacher at the Baumberge Schule (Fig. 5.162).

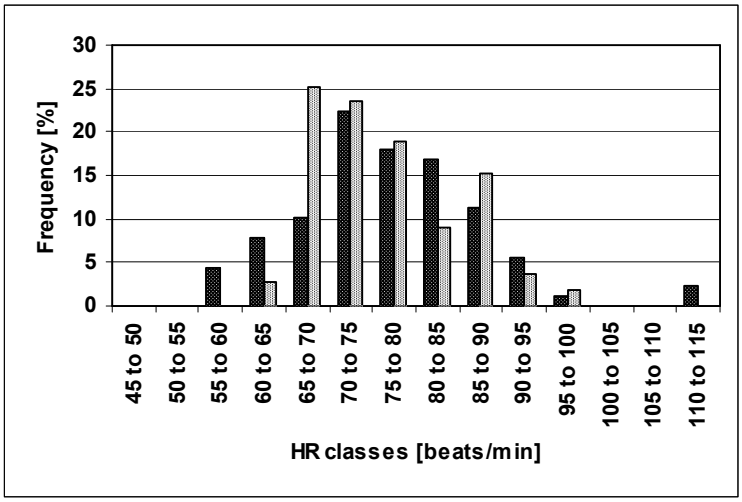

Fig. 5.161 Distribution of the basic activation in phases with dT > 50 %, sorted according to classes with RT > 0.5s (▓) and RT< 0.5s (▒), (n = 12 teachers); Grundschule Stichnathstraße

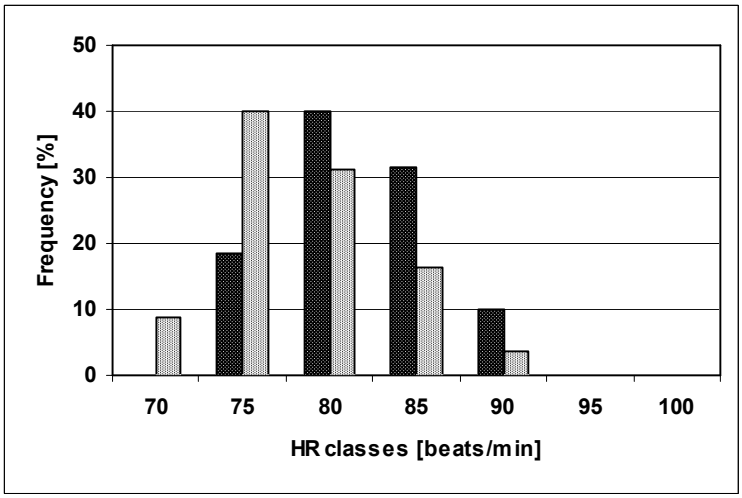

Fig. 5.162 Distribution of the basic activation in phases with dT > 50 %, sorted before (▓) and after (▒) the refurbishment, (n = 1 teacher); Baumberge Schule

The inter-individual differences shown for the staff of the Grundschule Stichnathstraße are confirmed by the intra-individual reaction in the single case (Baumberge Schule). In both cases a shift to a lower activation by one class interval is revealed. The distribution of the basic activation is represented below including for teaching phases with a high proportion of student-centred teaching. Figure 5.163 shows the result for the teacher group from the Grundschule Stichnathstraße:

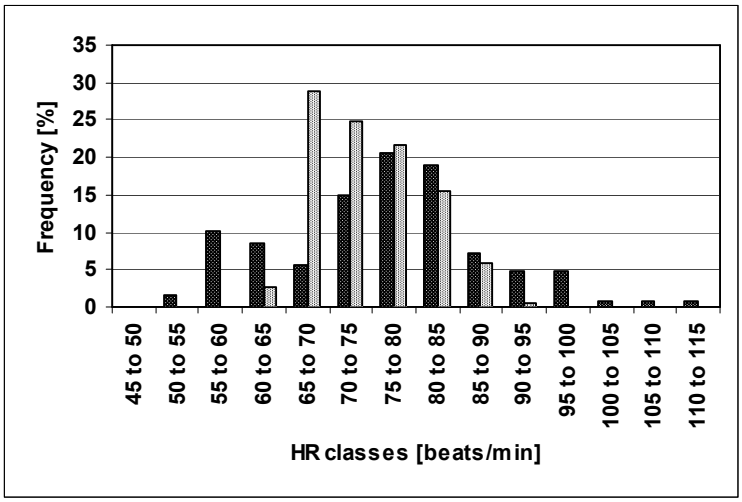

Fig. 5.163 Distribution of the basic activation in phases with scT > 50 %, sorted according to classes with RT > 0.5s (▓) and RT < 0.5s (▒), (n = 12 teachers); Grundschule Stichnathstraße

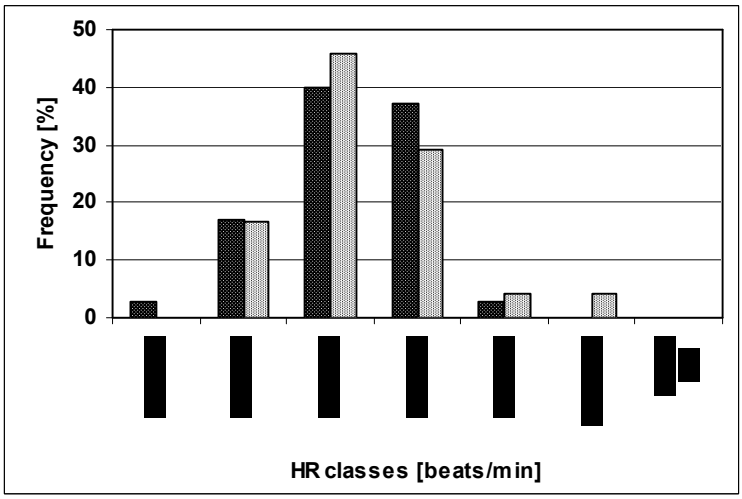

Fig. 5.164 Distribution of the basic activation in phases with scT > 50 %, sorted before (▓) and after (▒) the refurbishment, (n = 1 teacher); Baumberge Schule

Here the influence of the better room acoustics and/or speech intelligibility on the basic activation is clearer. The maximum distribution over two class intervals – corresponding to 10 beats per minute – is lower than under poorer conditions. Even in the case of the teacher from the Baumberge Schule it is possible to detect a shift within the two classes 80-90 [beats/min] (Fig. 5.164). However this effect is substantially less than under direct teaching conditions and shows the clear pedagogical preference of the teacher. However, this finding confirms the above

assumption, that the result of the purely lesson-based average-value analysis (see once again Fig. 5.158) reflects to an unsatisfactory degree the relationships between a room's acoustic working conditions and load during student-centred teaching methods.
The question of the average stress caused by teaching and/or the basic tension in the form of the basic level of activation the fatigue and/or activation behaviour of the teacher has been analysed in the previous sections.
This question of whether fatigue processes are more extreme under specific working conditions, should be addressed again with respect to the broader aspect of good (RT < 0.5 s) and/or bad (RT > 0.5 s) room acoustics. For the Grundschule Stichnathstraße the distribution of the 5min heart rate trend is shown for the working phases with a predominant share of direct teaching for all teachers in Figure 5.165.

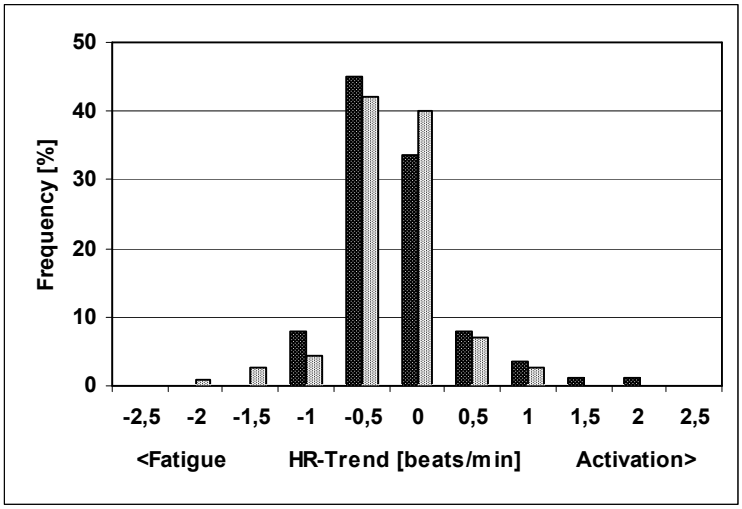

Fig. 5.165 Distribution of the HR-trend$_{5min}$ in phases with dT > 50 %, sorted according to classes with RT > 0.5s (▓) and RT < 0.5s (▒), (n = 12 teachers); Grundschule Stichnathstraße

The difference between the two groups can be detected in this class interval as a shift within the two average classes (-0.5 by 0 and 0 by 0.5): The ratio of fatigue to activation tends to be level under better acoustic conditions (top floor) while the fatigue rates predominate in the other rooms (ground floor). The same thing applies for the teacher in the Baumberge Schule (Fig. 5.166): Here again the shares of activation and fatigue are even under the good acoustic conditions, while the fatigue rates before the refurbishment are double.
An even clearer result is shown for the phases with a predominant share of student-centred teaching methods – at least for the Grundschule Stichnathstraße – (Fig. 5.168). There is even a reversal of the distribution between the two groups of classrooms in relation to the two average classes within the distribution. While a considerably greater share of fatigue is to be found under poorer acoustic conditions, a higher share of activation can be found under the better conditions on the top floor (RT < 0.5 s). This is not evident in the case of the teacher at the Baumberge Schule (Fig. 5.167). It reflects once again her basic dislike of student-centred teaching – and it also leads to a comparably lesser proportion of this teaching method within her overall teaching. It is worth noting that the resulting low n suggests that a greater degree uncertainty be taken into account when evaluating the results from the Baumberge Schule with regard to this question.

Very different personal responses can be given in this type of analysis due to the non-specific reaction of the heart rate to each type of stimulus. In a field study this should be compensated by a data record as representative as possible and where results differ for the present question it is worth focussing more attention on the larger data record from the Grundschule Stichnathstraße.

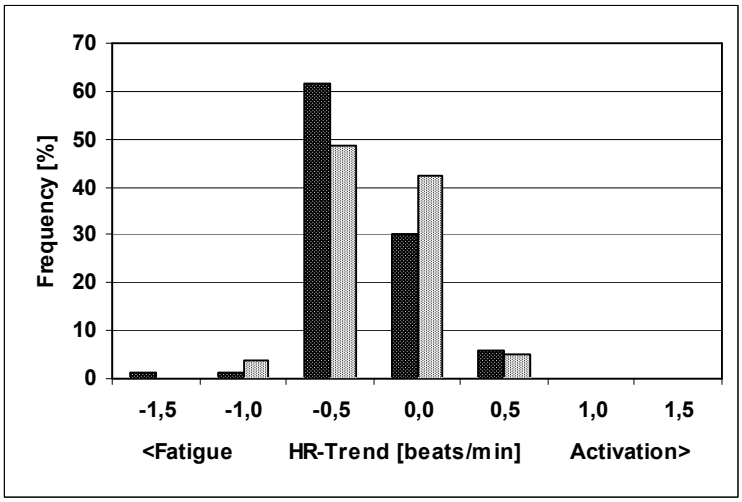

Fig. 5.166 Distribution of the HR-trend$_{5min}$ in phases with dT > 50 %, sorted before (▓) and after (▒) the refurbishment, (n = 1 teacher); Baumberge Schule

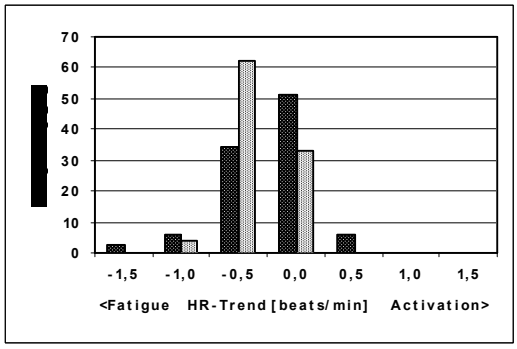

Fig. 5.167 Distribution of the HR-trend$_{5min}$ in phases with scT > 50 %, sorted before (▓) and after (▒) the refurbishment, (n = 1 teacher); Baumberge Schule

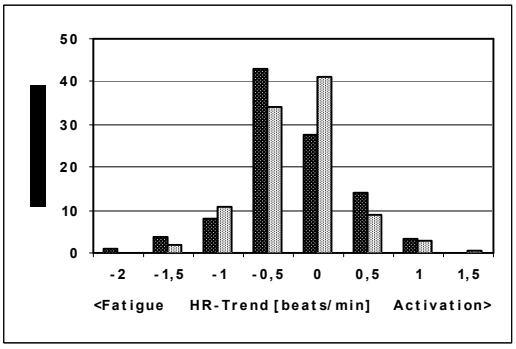

Fig. 5.168 Distribution of the HR-trend$_{5min}$ in phases with scT > 50 %, sorted according to classes with RT > 0.5s (▓) and RT < 0.5s (▒), (n = 12 teachers); Grundschule Stichnathstraße

To summarise the previous analyses, however, it can be safely asserted, at least in an overall observation, that the average stress level is less under better acoustic working conditions than under poor acoustic conditions during direct teaching phases and even more so during student-centred working phases.

5.3 Synopsis – analysis of the mutual dependence of the reaction values in the context of different teaching methods

Finally, an overall presentation of the results is attempted based on selected real examples, which synoptically compare the influences of the two filter values, room acoustics and pedagogical teaching method. For one last time the monitored data from the Baumberge Schule supplies the basis for a qualified comparison. The comparison of two situations, before and after the intervention (refurbishment of the room acoustics), is possible here with no major gaps in the data record. This cannot normally be taken for granted in a field study without corrective intervention. The following analyses are based on two mornings during which practically identical teaching timetables were used in each of the two investigation weeks before and after the refurbishment: Tuesday and Thursday.
In this final stage of the evaluation, the central question is still the significance of the room acoustics for the teaching process and the impact on the stress of the teacher. However, a broad statistical approach is avoided this time. The methodology this time comprises the comparison of individual corresponding teaching situations.
Thus Figure 5.169 shows the progression of the noise level in teaching over the Tuesday morning from the 1st to the 4th lesson. For ease of legibility the lessons concerned are indicated with solid lines. The progression over the period based on a single actual example on this day shows the same reduction of the noise level after the refurbishment that was shown in the statistical analyses in the previous section.

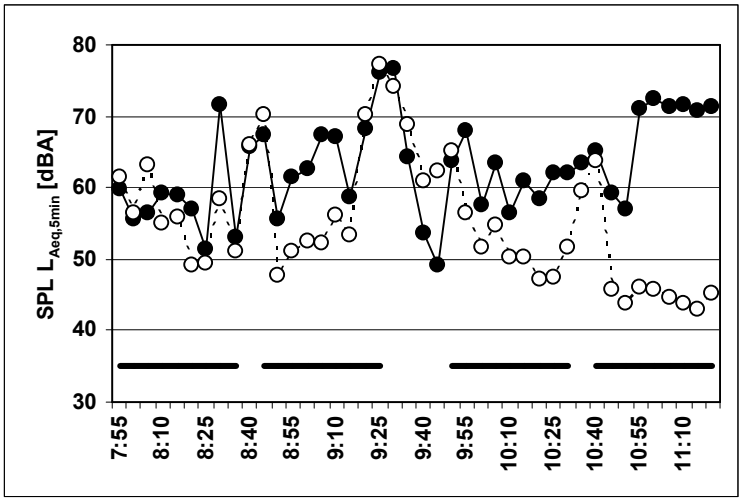

Fig. 5.169 Working SPL in teaching (Tue. 1st – 4th lessons) before (●) and after (○) the refurbishment; Baumberge Schule

The timetable for the first three lessons is the same in both weeks; language, general knowledge and mathematics. The fourth lesson (general knowledge in the first week) is not available for comparison since the pupils were free for this period in the second week. The synchronous course of the noise level is significant for the comparison. The noise trend in the classroom was similar in both weeks but took place at different levels. The lessons were considerably quieter after the refurbishment. The general results of the previous analysis in section 5.2.1 are also shown here.

How does the teachers stress appear in relation to this? Figure 5.170 shows the course of the heart rate over this teaching phase for the times before and after the refurbishment of the classroom.
A global observation of the course of stress over the teaching day shows a strikingly synchronous progression. The level difference in this individual case corresponds with the statistical analysis in section 5.2.2. The major difference in the 4th lesson is due to the different teacher activity in the free period (staying in the staff room?). Nevertheless the significant increase in stress in the 4th period, the general knowledge lesson, before the refurbishment is very striking: In this period the teacher spent a long time employing student-centred teaching method, which she appears to dislike. This phenomenon has been shown in the previous analysis.

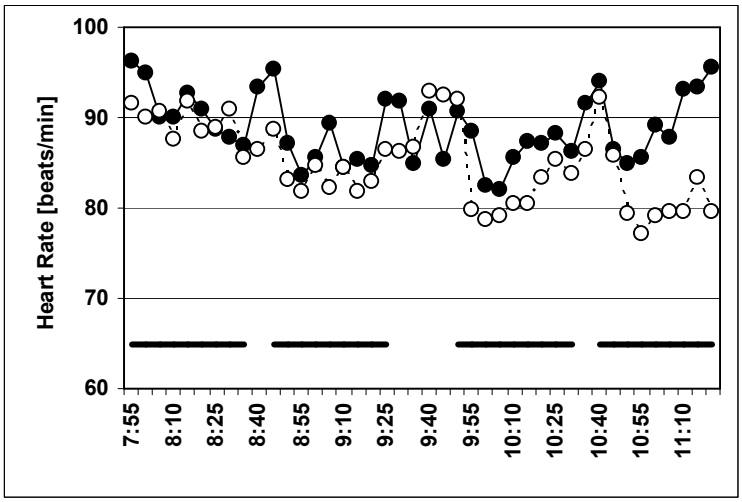

Fig. 5.170 Average stress in the course of the day (Tue., 1st– 4th lessons) before (●) and after (○) the refurbishment

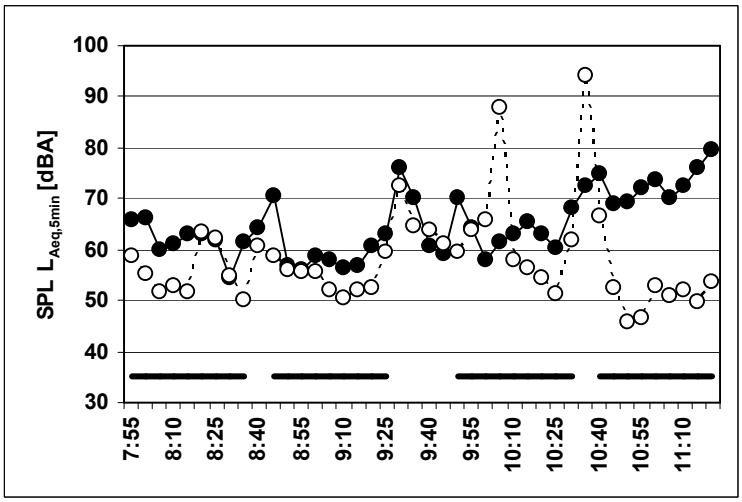

Fig. 5.171 Working SPL in teaching (Thur. 1st – 4th lessons) before (●) and after (○) the refurbishment

Another period that lends itself to direct comparison is Thursday morning. The first two lessons featured identical subjects both weeks (language and mathematics). The

data for the 3rd lessons however are incorrect or absent and the 4th lesson is "general knowledge" before the refurbishment and "religion" after the refurbishment. The course of the working SPL shows once again the largely synchronous progression on a different level (Fig. 5.171). The 4th lesson is once more left out of the equation as both the subject and the teaching method differ. Overall, as already shown for Tuesday, one can see a clear trend both for the noise level development and for the heart rate, particularly in the first two lessons. (Fig. 5.172).

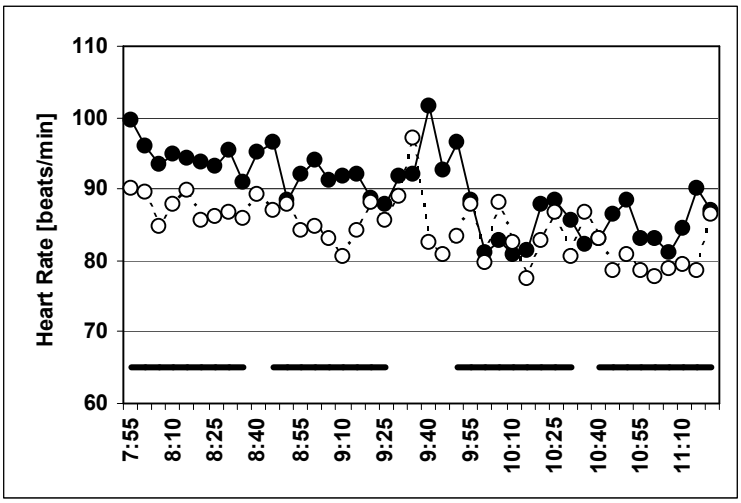

Fig. 5.172 Average stress in the course of the day (Thurs., 1st – 4th lessons) before (●) and after (○) the refurbishment

Since the stress is a consequence of the load, and the noise level in teaching is a substantial characteristic of this load, the two values are once again compared directly in the analysis of the two selected days that follows (Fig. 5.173 - 5.176).

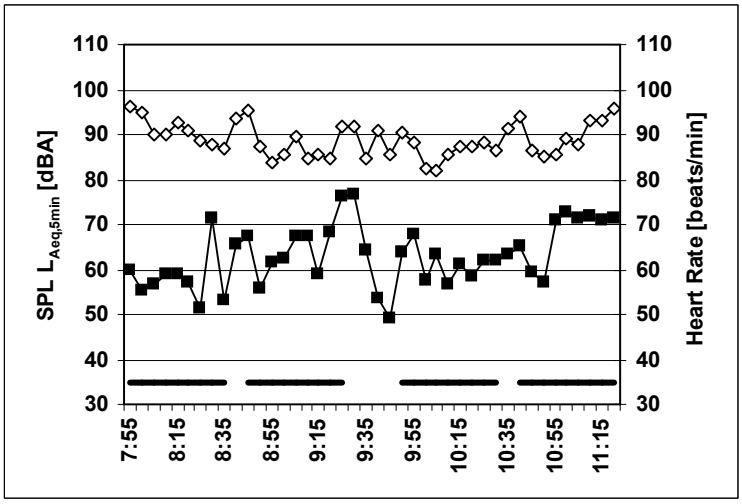

Fig. 5.173 Average stress (◊) and SPL (■) in the course of the day (Tue. 1st – 4th lessons) before the refurbishment

What influence therefore does noise in the classroom have on the stress of the teacher? The comparison of the curves for both parameters reveals certain similarities at least within broad ranges. For example, the rise of the noise level over

the 3rd lesson on the Tuesday before the refurbishment very obviously results in a rise in the heart rate. On the same day in the 2nd lesson both the two maximum values and the two minimum values fall within the same parameters at the same time. There are also clear similarities in the trends of the two parameters on the other days. One must however take into consideration the fact that other load factors play their part in these situations.

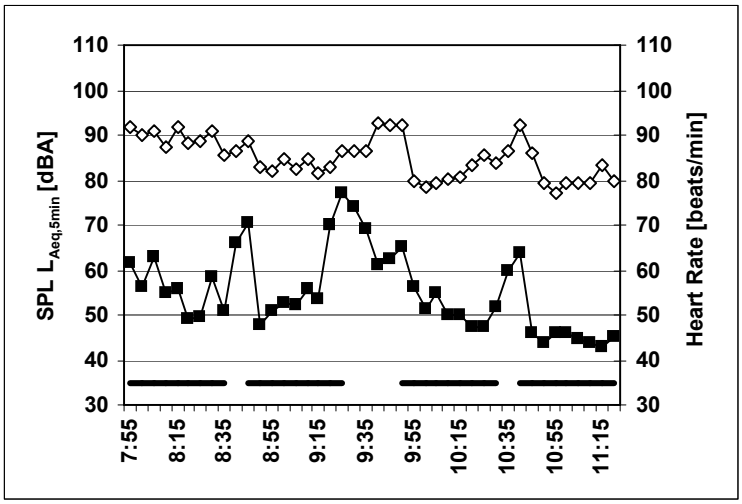

Fig. 5.174 Average stress (◊) and SPL (■) in the course of the day (Tue. 1st – 4th lessons) after the refurbishment

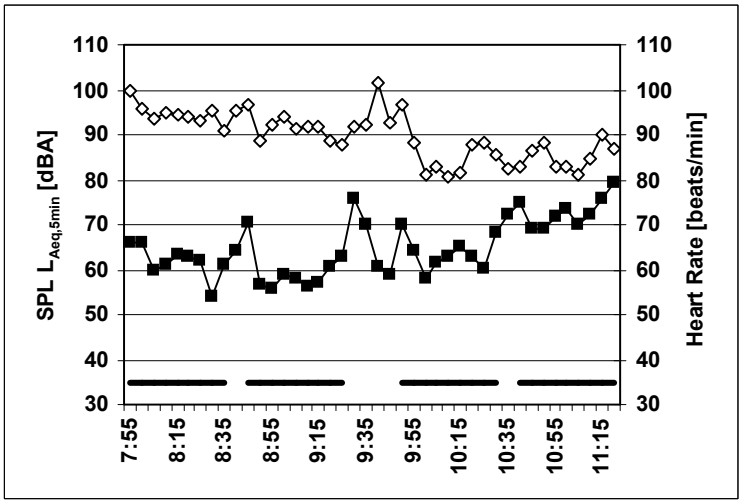

Fig. 5.175 Average stress (◊) and SPL (■) in the course of the day (Tue. 1st – 4th lessons) before the refurbishment

However, while strictly reproducible investigative situations per se can only be created in the laboratory, the present data record from the "monitored field" clearly shows a close link between the stress response and the load value "noise level". The comparability of the respective teaching units based on the teaching grid can certainly be comprehended and/or verified.

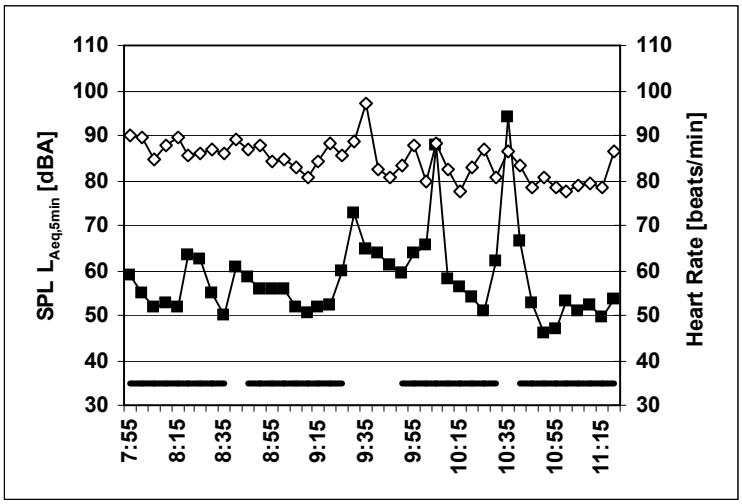

Fig. 5.176 Average stress (◊) and SPL (■) in the course of the day (Tue. 1st – 4th lessons) after the refurbishment

For the "Thursday" example there follows a comparison of the results of the teaching observation for the first two and the fourth lessons in order to verify the similarity of the teaching situation over the whole lesson. It shows the respective shares of teaching methods and shares of speech with respect to time. Figures 5.177 to 5.179 show the respective teaching grids for the Thursday which show a) the lesson before the refurbishment and b) the corresponding lesson after the refurbishment.

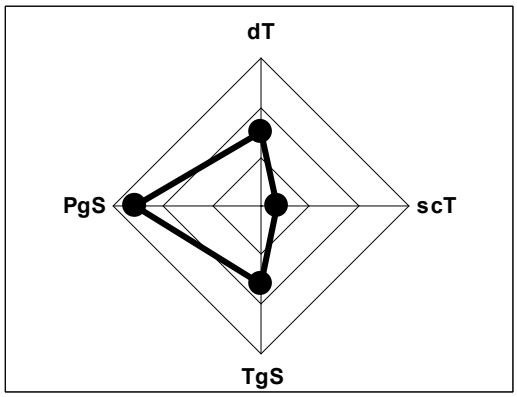

Fig. 5.177a Thursday, before renovation, 1st lesson

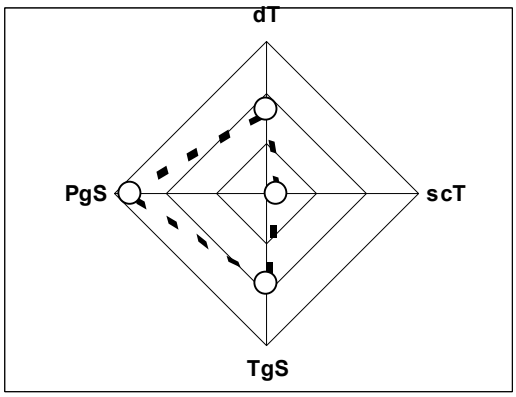

Fig. 5.177b Thursday, after renovation, 1st lesson

There is a strikingly close agreement of the grids for the 1st and 2nd lessons, which confirms the very close similarity of the teaching methods. However, an almost opposite teaching method can be observed in the 4th lesson and is due to the change in the timetable mentioned earlier. The "general knowledge" lesson (before the refurbishment) was replaced with "religious education" after the refurbishment. While practically all of the general knowledge lesson was dominated by student-centred teaching methods, the religious education period apparently involved none.

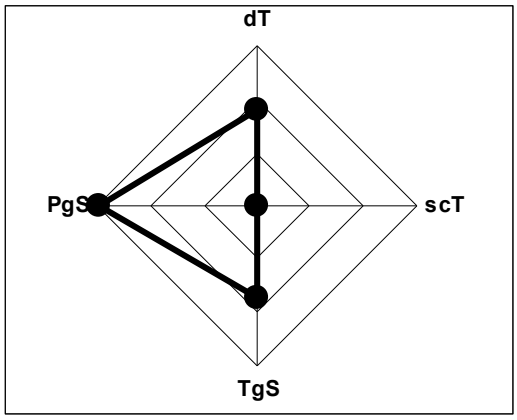

Fig. 5.178a Thursday, before renovation, 2nd lesson

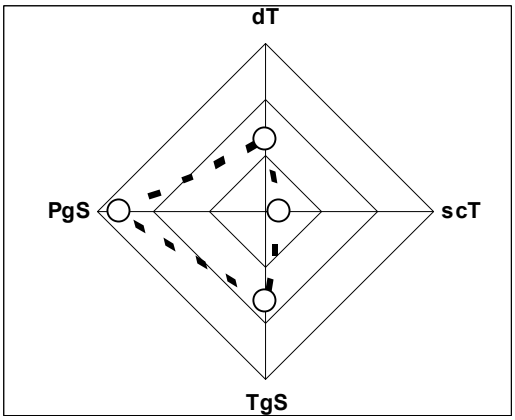

Fig. 5.178b Thursday, after renovation, 2nd lesson

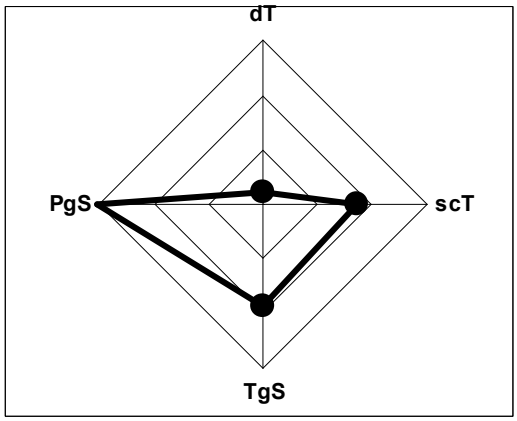

Fig. 5.179a Thursday, before renovation, 4th lesson

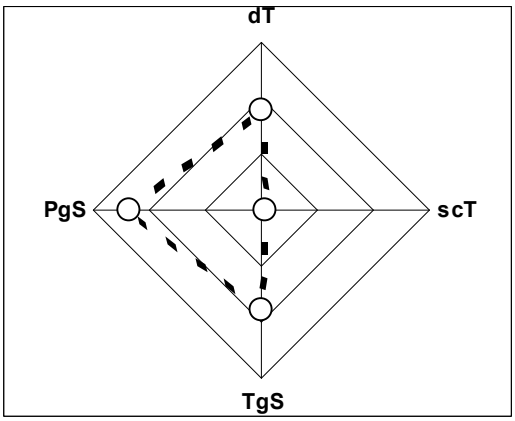

Fig. 5.179b Thursday, after renovation, 4th lesson

This ultimately provides a solid methodological basis for a detailed calculation of the correlation between the heart rate as a stress value and the working SPL for these six selected teaching units. It does not seem sensible to analyse the whole daily structure for this purpose as there are too many un-monitored interruptions (e.g. breaks etc.). Fig. 5.180 to 5.183 show the respective average stress (HR_{av5min}) as a function of the working SPL ($L_{Aeq,5min}$) for each of these six lessons in 5min time slices.

Each of the ellipses combines the data for a single lesson. The axes of the ellipses in each illustration correspond to the regression lines.

In the overall view of the three lessons on the Thursday before the refurbishment (Fig. 5.180) two things immediately catch the eye. Firstly, the shift of the ellipses to the right represent the increase of the working SPL over the school morning and secondly the drop in the stress level as a consequence of fatigue, as described in section 5.2.2. Within the individual lessons however, the position of the ellipses show that without exception the rise of the noise level led to an increase in the heart rate and an associated increase in the load.

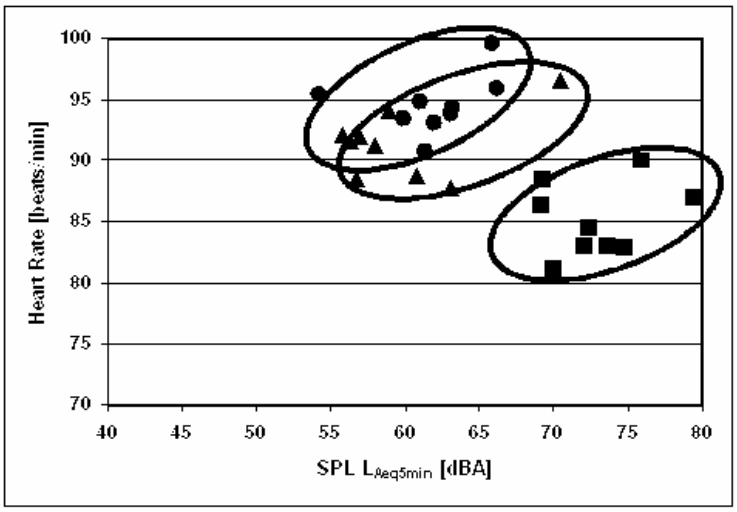

Fig. 5.180 Average stress in relation to the working SPL, 1st (●), 2nd (▲), 4th (■) lessons, Thursday before the refurbishment

Figures 5.181 to 5.183 finally show the situation for each of these three lessons before and after the refurbishment. For the 1st and 2nd lesson one can see the reduction of both the working SPL as well as stress under the improved acoustic working environment. In addition, the rise in the heart rate in relation to the noise level after the refurbishment is less than previously (lower angle of gradient of ellipse). This indicates less sensitivity with respect to the load factor of noise under optimum acoustic framework conditions. It is not possible at this juncture to clarify whether this is due to better speech intelligibility or the reduction in the noise level.
It is practically impossible to make a direct deduction for the 4th lesson due to the different subjects and the different teaching methods used for each. Nevertheless, the table once again shows a reduction of the noise level and the heart rate and a reduction of the sensitivity.

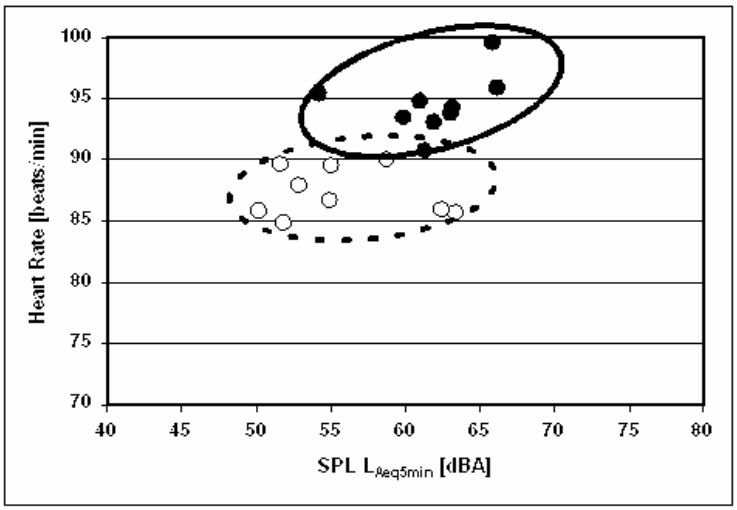

Fig. 5.181 Thursday 1st lesson "language" before (●) and after (○) the refurbishment

There has been enough said already about the general tendency of the teacher to experience less stress when using a predominantly direct teaching method. However,

the direct lesson comparison also shows that the teacher achieves an extremely quiet and concentrated working atmosphere with this teaching method. The working SPL during the religious education lesson with 5-min average values of between 45 and 55 dB(A) and one stray value of 65 dB(A) are almost sensationally low.

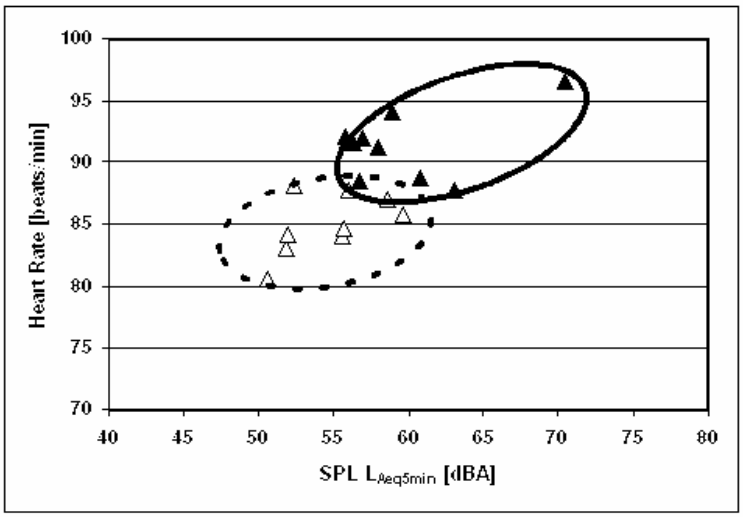

Fig. 5.182 Thursday 2nd lesson "mathematics" before (●) and after (○) the refurbishment

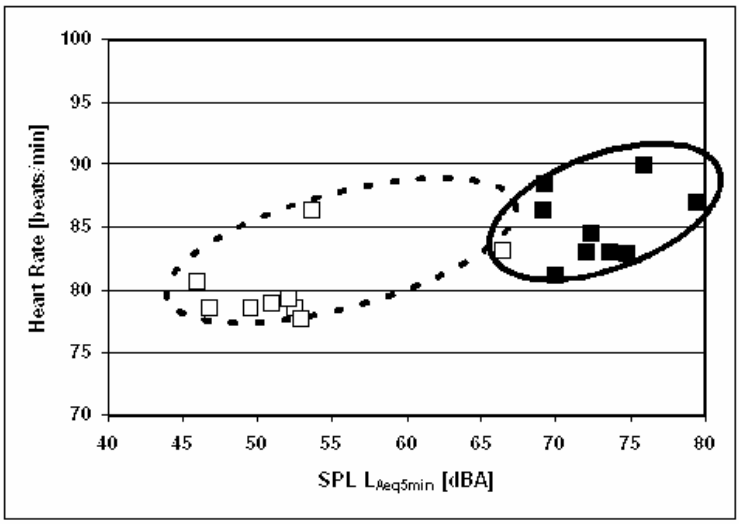

Fig. 5.183 Thursday 4th lesson "general knowledge/religion", before (■) and after (□) the refurbishment

The impact of the room acoustic refurbishment shown here can be shown in the second selected example, the first two observed lessons on the Tuesday, in which the same subjects, language and general knowledge were taught in both weeks. A slight increase in the direct teaching method is shown for the 1st lesson (language) (Fig. 5.184) while there is no change in the student-centred teaching method. A decrease in the student-generated speech can also be determined. For the 2nd lesson (general knowledge) (Fig. 5.185) the lesson composition is almost identical with regard to teaching method and shares of speech.

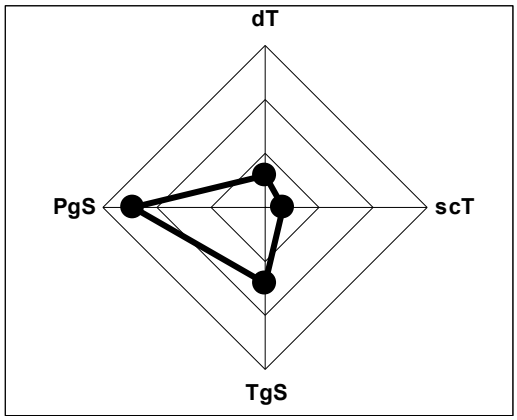

Fig. 5.184a Tuesday, before refurbishment, 1st lesson

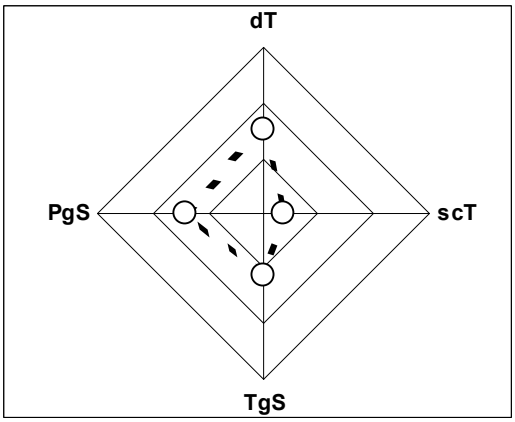

Fig. 5.184b Tuesday, after refurbishment, 1st lesson

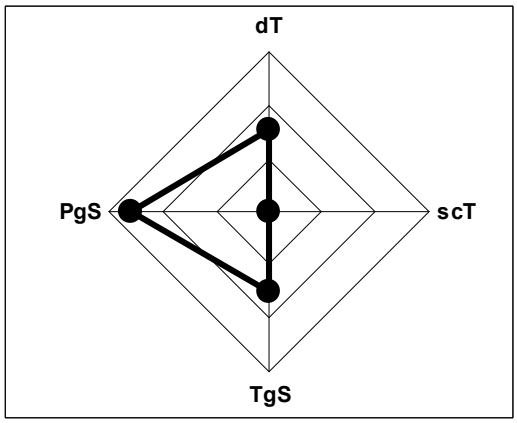

Fig. 5.185a Tuesday, before refurbishment, 2nd lesson

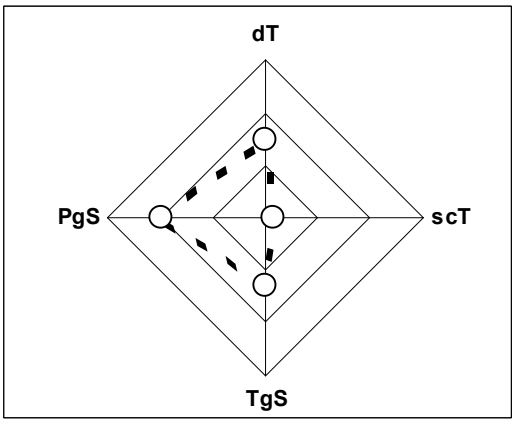

Fig. 5.185b Tuesday, after refurbishment, 2nd lesson

Figure 5.186 again shows the relationship between the working SPL and the stress response of the teacher. The data for the respective lessons, recorded into 5 min. time slices, is again incorporated into an ellipse. The radii of the ellipses give the distribution of data in both dimensions while the axes correspond to the regression rates.

This illustration clearly shows on the one hand the fatigue effect over the series of lessons and on the other the influence of the room acoustic refurbishment. The values for the second week are lower than before in both dimensions. Figure 5.187 shows the same data as in Figure 5.186 again. Only the regression lines are transcribed this time. Their increase is a measurement of noise sensitivity. They indicate by how many beats per minute the stress in the form of the heart rate increases when the working SPL changes. The reduction of sensitivity to noise under the better acoustic conditions after the refurbishment is thus clearly verified.

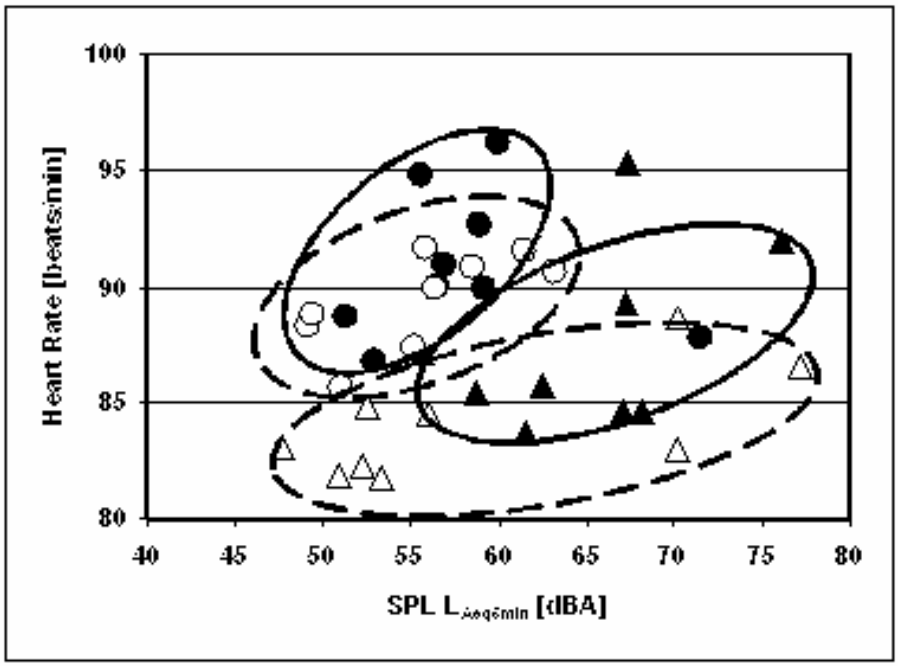

Fig. 5.186 Relationship between stress and working SPL on the Tuesday before (●▲) and after (○Δ) the refurbishment, 1st (●○) and 2nd (▲Δ) lessons.

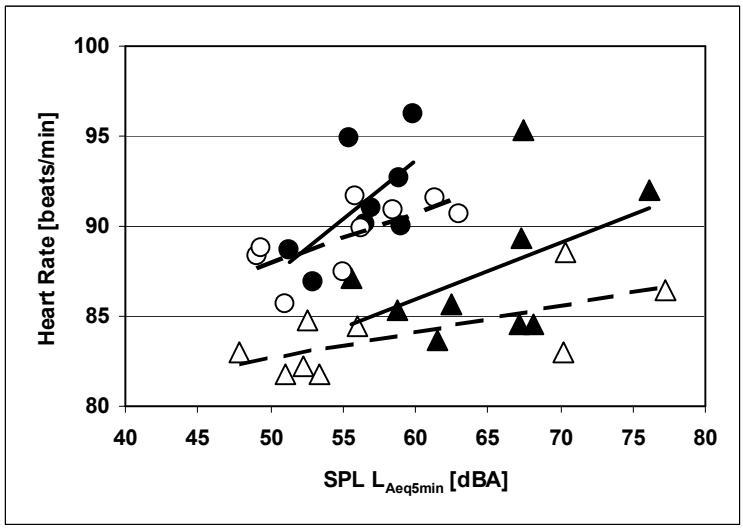

Fig. 5.187 Relationship between stress and working SPL on the Tuesday before (●▲) and after (○Δ) the refurbishment, 1st (●○) and 2nd (▲Δ) lessons with regression lines

Finally, for precisely this reason it is once again worth combining the evaluation of the effects of the room acoustics on teaching and the resulting stress of the teacher working under these conditions with separate observations of the two typical "direct" or "student-centred" teaching methods.

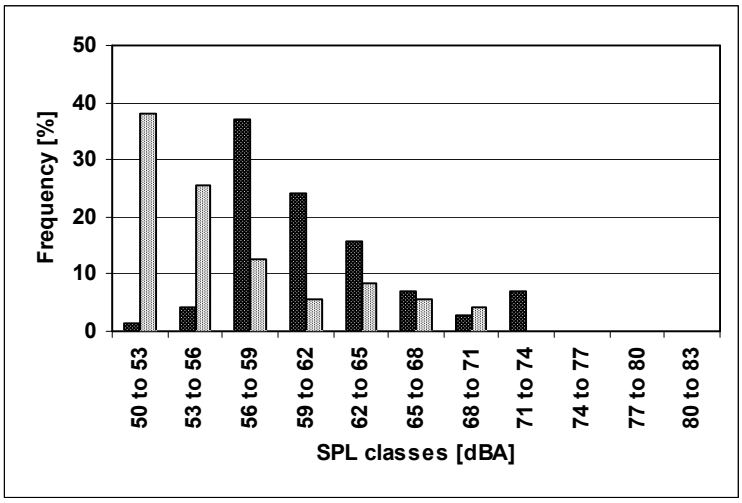

Fig. 5.188 Distribution of the working SPL in phases with dT > 50 % before (▓) and after (▒) the refurbishment

The overall view of the two teaching weeks in which the ISF project team were able to accompany the teacher in the Baumberge Schule also provides a striking picture (for the position at the outset, see again section 5.2.1 and section 5.2.2): The change of the ergonomic working conditions – in this case in the form of reduced reverberation time and/or increased speech intelligibility – led both during direct teaching as well as during student-centred teaching to a reduction of the working SPL on the one hand and the teacher stress on the other.
Figure 5.188 once again shows the distribution of the working SPL in the class observed at the Baumberge Schule in dT-dominated phases before and after the refurbishment.

While the maximum distribution before the refurbishment lay within the "56 to 59 dB(A)" range, it is 6 dB lower after the refurbishment. With respect to an accepted average speech volume of an adult of around 62 dB(A) this means:

RT > 0.5 s	*n = 70*	*67.1 % under 62 dB(A)*
RT < 0.5 s	*n = 71*	*81.7 % under 62 dB(A)*

Figure 5.189 shows the distribution of the average stress for the same working phases. As previously, at average stress levels the maximum distribution in the class "85 to 95 [1/min]" falls both before as well as after refurbishment. If, however, one compares the time slices in which the stress was below the value of 90 [1/min] a clear picture of reduced stress nevertheless emerges.

RT > 0.5 s	*n = 70*	*60.0 % under 90 [beats/min]*
RT < 0.5 s	*n = 80*	*82.5 % under 90 [beats/min]*

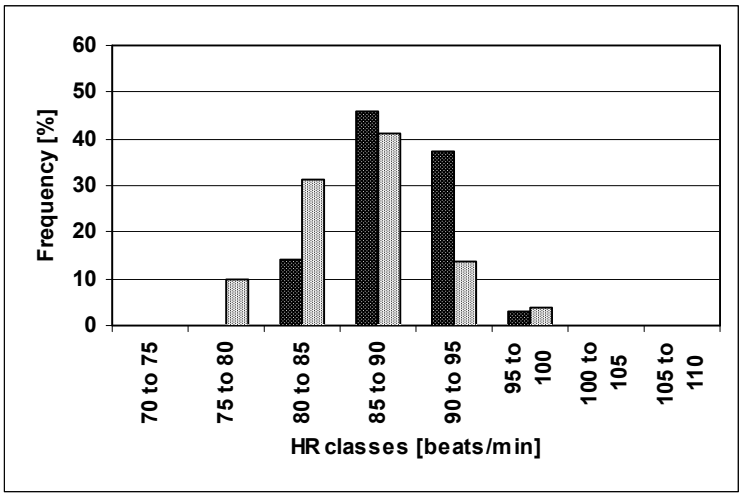

Fig. 5.189 Distribution of the average stress in phases with dT > 50 % before (▓) and after (▒) the refurbishment

In an observation of the maximum noise level values during student-centred working phases (Fig. 5.190) there possibly arises a irritating picture thanks to the distinct clustering within the lowest class "50 by 53 dB(A)". The cumulative observation of the volume levels under 62 dB(A) (see above) illustrates this fact much more clearly. It shows a practical doubling of the share in which comparably quiet conversation prevailed. A greater fluctuation range may be taken into account thanks to the considerably reduced overall share.

RT > 0.5 s	*n = 35*	*31.4 % under 62 dB(A)*
RT < 0.5 s	*n = 15*	*60.0 % under 62 dB(A)*

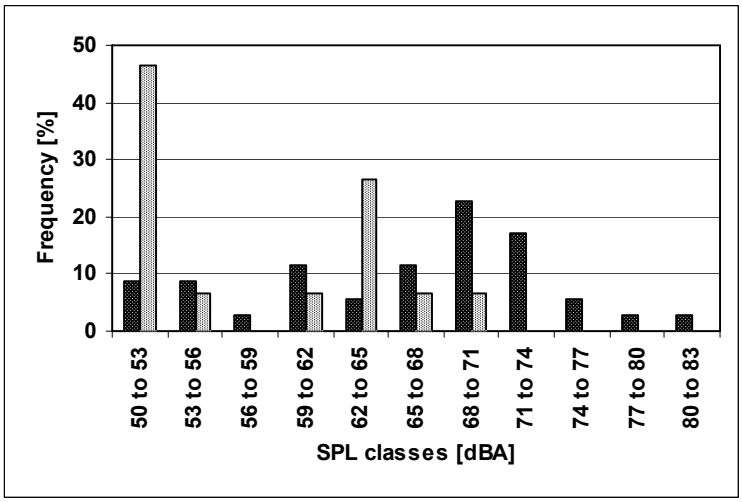

Fig. 5.190 Distribution of the working SPL in phases with scT > 50 % before (▓) and after (▒) the refurbishment

Even the difference in the distribution of the average stress (Fig. 5.191) falls considerably less during the student-centred working phases than during the direct

teaching phases. Nevertheless even here the cumulative distribution of the data, related to the value 90 [beats/min], reveals the reduction of the stress.

RT > 0.5 s	*n = 35*	*57.1 % under 90 [beats/min]*
RT < 0.5 s	*n = 24*	*62.5 % under 90 [beats/min]*

From the overall view of the results from the previous analyses one is justified in speculating that the effect during student-centred working phases for some teachers from the Grundschule Stichnathstraße would have been even higher (and possibly lower during direct working phases?).
The results of the previous statistical analyses are also reflected at the individual level. Even in the individual lesson – during both teaching methods – it is possible to detect the effect of the basic room acoustic conditions on the noise level and the stress of the teaching staff. The two parameters behave in a strikingly parallel manner. A relationship between the two values can be assumed as being more than substantiated. The so-called "quiet noise" is directly reflected in the stress of the teacher.
As shown in chapter 2.3.1, all noise involves a stress-inducing factor, i.e. load value. It is therefore understandable that the stress response to a stress-inducing factor that is increasing in intensity also becomes stronger. The relationship identified here can be interpreted as follows: The heart rate increases as the noise level increases.

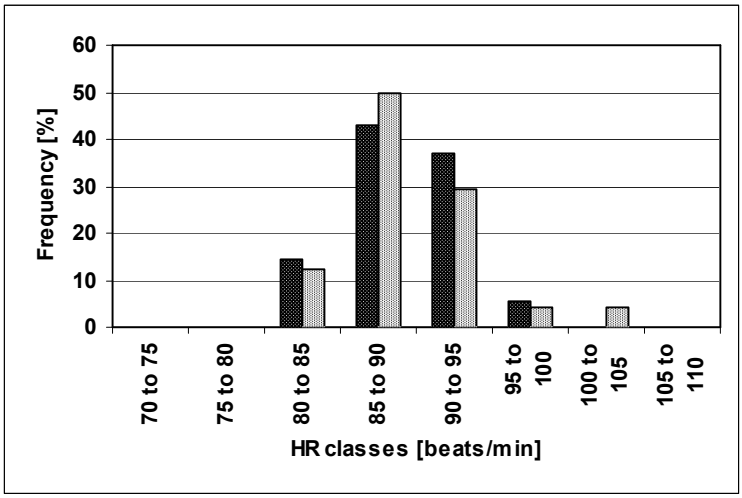

Fig. 5.191 Distribution of the average stress in phases with scT > 50 % before (▓) and after (▒) the refurbishment

This relationship is clearly demonstrable for the individual lesson. The interpretation of this difference between the individual lessons is based on the model of SUST AND LAZARUS (1997), according to which a continuous deregulation leads to a tonic shift which is reflected as fatigue or activation. That the sensitivity of this deregulation can also be influenced by other parameters is shown very clearly by the comparison of the lessons before and after the refurbishment. The better room acoustics result in considerably less sensitivity to noise and thus the effect of noise as a stress-inducing factor is reduced. The other influential values can be assumed to be constant.

5.4 Excursus: Survey of subjective sensitivity to noise

Within the context of the "Belastung und Beanspruchung von Lehrerinnen und Lehrern " (workload and stress of teachers) project (see SCHÖNWÄLDER ET AL., 2003) over 80 % of the 1,159 teachers surveyed responded to the statement that "the noise that pupils make" caused a subjective load (no. 105 of the load survey) with "true". The quality of this subjective appraisal of the "noise" factor was to be tested by the corresponding appraisal of a real teaching situation, which was accompanied by a noise level measurement. Since the appraisal of the "volume" of a lesson relates to the full period and not to individual time slices, the appraisal can be directly compared only with the average level of the lesson as a whole. On the other hand it is conceivable that only a few particular remembered situations are of significance for the appraisal. These might have been unpleasantly loud or unusually quiet working phases. There is also a tonic component of sensitivity as observed by SCHÖNWÄLDER ET AL. (2003) in the course of a teaching day. This effect may be due to increasing fatigue or a cumulative sensitivity to noise. A comparison of teachers' sensitivity to noise using ZIMMER AND ELLERMEIER'S (1997) noise-sensitivity questionnaire according to Schönwälder et al. (2004) revealed no relationship between the subjective appraisals and the actual volume of a lesson.
The subjective "volume" evaluation of the teacher at the Baumberge Schule was recorded for every lesson of the week before and the week after the room acoustic refurbishment. Figure 5.192 shows the distribution of the subjective evaluation before and after the refurbishment.

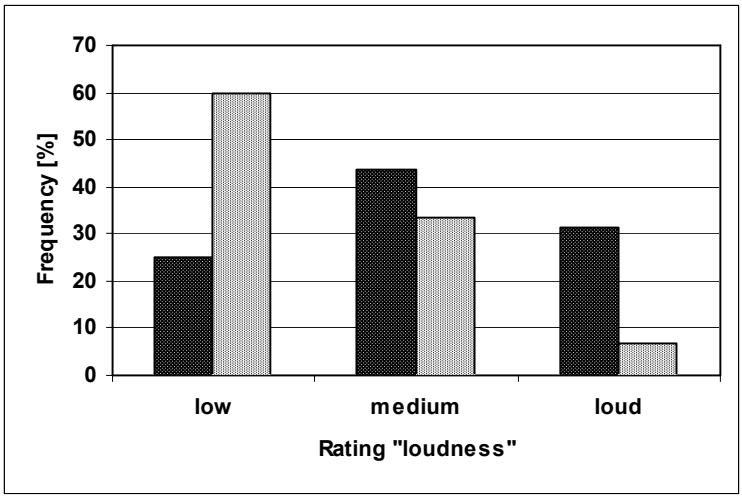

Fig. 5.192 Frequency of answers for the subjective evaluation of "volume", RT > 0.5s (▓) and RT < 0.5s (▒)

From this example one may draw the conclusion that the noise situation after the refurbishment is judged to be considerably quieter as compared to the situation before the refurbishment. The evaluation "loud" practically never occurs while 60 % of the lessons are judged to be "quiet". This one sided distribution after the refurbishment at least indicates a greater satisfaction with the overall situation. The fact that lessons have become generally quieter with the same distribution over the lessons might suggest a straightforward shift of the "volume" appraisal but not the kind of lopsided distribution that is shown above.

Figure 5.193 shows this teacher's volume appraisals for all the observed lessons, each in relation to the actual measured working SPL.

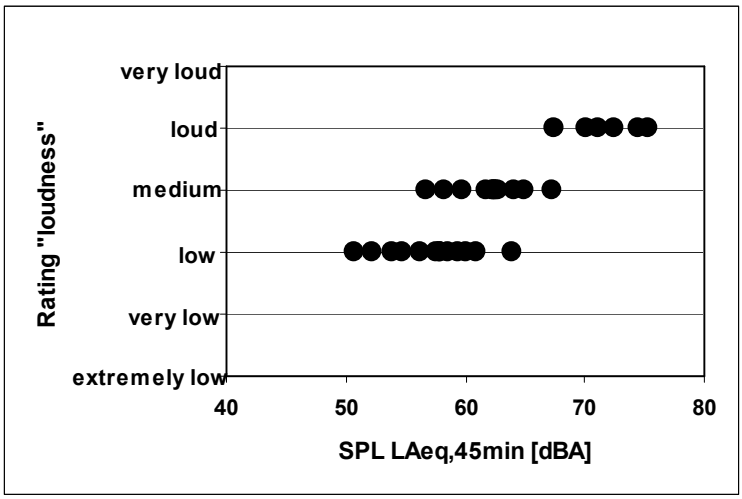

Fig. 5.193 Subjective evaluation of the "volume" in relation to the average level $L_{Aeq,45min}$

The figure clearly shows the very wide dispersion of the appraisal of the noise situation. There is no clear relationship between the subjective appraisal and the measured average level. Even the range from 55 to 65 dB(A) is rated both as "quiet" and "medium". Since this is the judgement of one and the same person, a very much greater dispersion must be expected from different people. The lopsided distribution in Figure 5.192 does not correspond to the distribution the average level, i.e., the discrepancy is based on the enormously large tolerance range of the evaluation, certainly on the evaluation of the overall situation and possibly also on a certain inhibition against using the "very quiet" category at all.
This kind of subjective evaluation of volume can certainly be used as a guide. Ultimately, however, surveys alone are not a reliable means of appraising the actual noise situation. However, this is not the context in which to embark on a discussion of what ultimately influences subjective appraisals.

6 Conclusions

1) As expected, both the working SPL and the basic SPL in both schools depended greatly on the room acoustics. The shorter the reverberation time and the better with that the speech intelligibility, the quieter the teaching occurs in the classroom. The respective relationships are within the examined classrooms with reverberation times between 0.3 s and 0.8 s virtually linear. The decrease in sound pressure level was about 2 dB per 0.1 s reduced reverberation time. The level reductions achieved in the Baumberge Schule were significantly greater than those mathematically expected as a result of installing the additional absorption surface during the refurbishment. By this the contribution to the reduction made by the change in the behaviour of the pupils became tangible. The pedagogical working methods were practically the same in both investigation weeks. Demonstrably, therefore, the reduction did not result from the fact, as might be assumed, that the pupils or teacher had spoken to one another quantitatively less in the second period of investigation. Since the temporal speech shares did not fall, however, the cause must lie in the reduction of the speech volume by all those involved. There was also another striking phenomenon. While the basic SPL in the Baumberge Schule before the refurbishment predominantly rose throughout the morning of lessons by an average 10 dB, this increase largely disappeared after the refurbishment.

2) The present data provides only limited confirmation of the assumption that pupil-centred teaching methods usually generate a greater working SPL than direct teaching methods. In fact the analysis of the data from the Baumberge Schule confirmed this impression very clearly, with level differences of approx. 5 dB between direct and non-direct teaching phases. However the data from the Grundschule Stichnathstraße did not confirm it with the same degree of clarity. Surprisingly, the different teaching methods in both schools barely differed with respect to the proportions of time that the teacher and/or pupils were speaking. Accordingly, direct teaching does not mean that the pupils are not involved in the event (key phrase: direct teaching and learning discussion). On the other hand, pupil-centred teaching does not mean that the teacher stops talking.

3) The noise-level reductions achieved by changes to the room acoustics in the Baumberge Schule were not the same for all teaching methods. In fact at an average of 12 dB, the level reductions during pupil-centred teaching phases in comparison to before the refurbishment were more than twice as high as the decrease of approx. 5 dB observed during direct teaching phases. If we assume a physical level reduction of around 3-4 dB it becomes clear that during direct teaching phases a majority of the reduction is achieved by physical absorption while during pupil-centred teaching phases a key factor is a changed, quieter, participant behaviour. The acoustic quality of the room is therefore of particular significance during pupil-centred teaching phases. While before the refurbishment the working SPL generally rose the greater the time spent engaged in pupil-centred teaching methods (see above), this relationship is no longer discernible under the improved room acoustic conditions (average reverberation time < 0.5 sec). In fact, on average, the pupil-centred teaching phases were even quieter than the direct teaching phases after the refurbishment.

4) The stress in teaching depends on the ergonomic parameter of room acoustics. The difference in the average stress levels and in the basic teacher activation was not only discernible in the Baumberge Schule with its easily monitored parameters (before and after refurbishment) but also in the two acoustically different storeys of the Grundschule Stichnathstraße. The difference, while sometimes only slight at average values, becomes clearer when one compares the frequency distribution of all the individual heart rate values. This relationship is even clearer in the distribution of the basic activation. Under the acoustically more favourable conditions on the top floor the basic level of stress is considerably less than with teaching staff working on the ground floor. In the Grundschule Stichnathstraße it is possible to observe an even distribution of fatigue and activation under the better acoustic conditions on the top floor (reverberation time approx. 0.5 sec) while fatigue predominates on the bottom floor with a 0.1 to 0.2 sec longer reverberation time. It is also possible to observe a reduction of fatigue after the refurbishment of the Baumberge Schule. It would naturally make sense to check fatigue on the basis of another parameter and although this was not included in the design of this project it is certainly a question for the future.

5) Stress in teaching depends both on the progress of the day as well as on the teaching methods. It is generally possible to observe a distinct fatigue effect over the school morning. However, this effect is lessened under better acoustic conditions (after the refurbishment at the Baumberge Schule, on the top floor of the Grundschule Stichnathstraße). With regard to teaching methods, above all the personal preferences of the teaching staff in the Baumberge Schule are evident in the heart rate. It is not possible to determine any dependencies in an observation of the average values of the mixed data from the Grundschule Stichnathstraße. However a detailed analysis of the distribution once again reveals reduced teacher stress levels during direct teaching phases. Since attentiveness processes lead to an increase in stress, this would be a possible explanation since during student-centred working, teachers need to monitor or direct many different working groups, while all pupils are treated as a single group during direct teaching. Similarly with regard to speech shares, and particularly in the case of the teacher at the Baumberge Schule, teachers are far less stressed when they are speaking themselves. Here again one needs to question with regard to the distribution of attentiveness whether speaking oneself is less stressful than "multiplied" listening.

6) The average stress levels of the teachers tend to fall less in the Grundschule Stichnathstraße under the better acoustic conditions on the top floor during both direct and student-centred teaching phases. There was also no obvious difference between the teaching phases (with regard to noise level for instance). The distribution of the basic activation in both schools was considerably less during both teaching methods in rooms with good acoustics. In both schools a reduction of fatigue was discernible during direct teaching under good acoustic conditions. For student-centred teaching phases this relationship is evident only at Grundschule Stichnathstraße (possibly a statistical artefact problem). The comparison of such student-centred teaching situations is only possible in relation to individuals. The available n is too small for a group comparison. Individual factors such as constitution, motor behaviour, behaviour pattern and many more play a significant role in such cases. These factors however, have not been taken into account for the individual teachers. Once again this underlines the particular significance of the investigation at the Baumberge Schule.

7) The synoptic link with the trends of individuals shows a clear relationship between stress response and "noise" in teaching. Tendential dependencies are revealed for individual lessons. If the working SPL in teaching falls due to improved room acoustics, the stress of the teaching staff is simultaneously reduced. The teacher's heart rate was 10 beats per minute less when she was teaching during the 5 to 10 dB quieter lesson. The changed sensitivity with respect to the stress caused by teaching observed at the Baumberge Schule can be clearly traced to the change of the acoustic ergonomics since all other conditions remained constant as far as this can be monitored in a field investigation. In a short-term laboratory experiment such processes of change in individuals are observed to a very limited degree, if at all.

8) Due to the reduced noise level in teaching, the ergonomic parameter of room acoustics was reflected doubly in the stress of the teaching staff. Along with the recorded reduction of the average heart rate, "sensitivity to noise" also changed. Under better acoustic conditions, the factor of noise was observed to have a less stressful effect. The teaching staff responded physiologically less severely to an equivalent noise level increase. Their heart rates increased considerably less. Within the terms of the stress model this means that the processing of the stress factor "noise", including when the noise is solely working noise, is influenced by both internal as well as external factors. The reduced noise level is possibly not causally responsible for the reduction of stress, rather it improves communication conditions. This, however, was not possible without intervening in the room acoustics. The linking of the influential factors is of decisive significance here, particularly over the period that this working process lasts. It is impossible to analyse the workplace merely on the basis of a snapshot. The process over time is of decisive significance for personal responses.

7 Consequences and Outlook for Occupational Science

The TOP model shown in Figure 7.1 is frequently used in the industrial sector in relation to occupational safety measures. It describes the different intervention levels concerning the risk to occupational safety and the effects that can be achieved by those measures (and is based per se on an *interdisciplinary* approach). It differentiates in principle between **t**echnical, **o**rganisational and **p**ersonnel-based solutions wherein it can be assumed that a solution is more effective the higher it is prioritised (see e.g. HARTUNG). It is for instance far more effective to reduce machine noise directly at its emission source than to protect affected persons by organisational means or even to equip personnel with hearing protection.

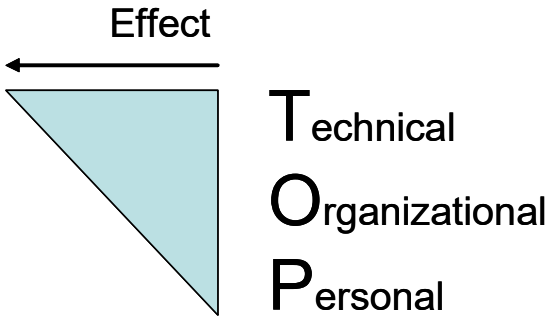

Fig. 7.1 TOP model used in occupational science (HARTUNG)

This model has not been applied to schools as far as we can tell from the literature we have encountered. It is possible that this again shows that occupational scientists do not normally consider a school building as a “workplace”, as rarely in fact as educational researchers and teachers employ the tools of occupational science.
Applying the model to schools could clarify some misunderstanding in the discussion on school noise. In fact, as far as we have experienced from numerous discussions on this subject – depending on to whom one is speaking – aspects from the various categories are frequently confused and inappropriately compared. Without well-founded classification this kind of confused position lacks focus – particularly when additional emotionally-charged aspects come into play. How is one to argue, for example, if the request for good room acoustic ergonomic working conditions (T) is “refused” with a succinct reference to the teacher's personality or “perhaps” lack of pedagogical qualifications (P). A reference back to the occupational safety TOP model clarifies the mechanics of such a debate. There are simply different priorities to consider. The commercial world is long-accustomed to the idea that those who have to pay for technical solutions like to attribute problems to organisational or personality factors.
And in the public debate about noise in schools those problems are more often associated with teacher deficits than with the classroom itself. However, teachers themselves are barely aware of the acoustic working environment in which they teach, as shown by the investigations of MCKENZIE AND AIREY (1999). Causal investigations are normally the last thing under consideration in education. At most, attentiveness is associated with the issue or organisation and therefore normally concentrates on characteristics such as class size or social behaviour. This is unjust.

The investigation of primary schools in the FIOSH (Federal Institute for Occupational Safety and Health) project “Lärm in Bildungsstätten” (noise in educational premises) (SCHÖNWÄLDER ET AL., 2004) showed that the school with the smallest class sizes of under 20 pupils was the loudest school despite good room acoustics (RT = 0.5 sec).

If one takes the TOP model seriously for schools, however, two fundamentally significant aspects of the issue become clear. Firstly it prohibits the phenomenon of "noise in schools" from being attributed to a single cause. Secondly it shows that different factors must play an active role in order to produce an environment in which good teaching can take place. In short, the ergonomic framework (T) must exist alongside a corresponding teaching (P) and organisational (O) concept.

It would of course be completely absurd to assert that teachers had no influence on the noise in their classrooms. They have of course – and they must use them. In their report on noise in educational establishments SCHÖNWÄLDER ET AL. (2004) address these possible influences in depth. The investigation also showed that level reductions of approx. 2 dB can be expected from pedagogical interventions of individual teaching staff within a short time. At the same time, with comparable room acoustic conditions and a comparable pupil social structure, comparable differences (5 to 6 dB) in the noise level were discerned between individual schools. The contexts were easily identifiable. Only those schools in which the staff pursued a unified pedagogical concept were really quiet. If the same rules of behaviour were applied not only in all classrooms and during the teaching but in all areas of the school, and the children – no matter which teacher they encountered – could expect a uniform response if they ignored these rules, this was consistently reflected in the measured noise level. The recipe is therefore as simple as promising but requires the cooperation and commitment of all the teaching staff. A lot of feedback from teachers in the course of this project saying that this is inconceivable amongst their colleagues is astonishing and really unacceptable. The need for a team-orientated approach has long been taken for granted in non-academic professions! One example is that the year-one pupils at the quietest of the two schools on average in the FIOSH investigation start their school life not with lessons, but with several weeks of socio-pedagogical training on behaviour in the school.

Education and training is therefore necessary – and not only for the pupils. We do not know whether such training forms part of the teacher training process. Emboldened by the two positive examples, however, we certainly trust teachers to cooperate and use their pedagogical expertise and experience to develop such programmes for their schools. A committed united approach appears to be of far more importance than the actual details of the programme. Nor do teachers need to start from scratch. There are numerous good teaching resources available, for instance from the “Bundeszentrale for gesundheitliche Aufklärung” (BZGA) (federal centre for health education), private institutions (e.g. Lernen statt Lärmen e.V.; UfU e.V. etc.), public sector accident insurers or trade associations. Access to information and materials is also available from the INQA (Initiative for the new quality of work) of the FIOSH. Ideas can be found from interesting pilot projects including “Schule des Hörens” (learning to listen), “Zuhören lernen” (listening and learning), “Ganz Ohr sein” (all ears) and even listening clubs organised by some radio stations.
The organisational and personal contributions to reducing noise in schools must not be overlooked. Even optimum ergonomic conditions only provide a framework for the pedagogical activities during the school day. It is however – as shown extraordinarily

clearly by the investigations – also essential for the success of the pedagogical efforts. Neither of the two aspects can be replaced nor offset by the other. They are mutually interdependent and need to interact to allow teaching to function, particularly in the context of the changes in communication.

One therefore returns to the question of responsibility. This may be otherwise expressed as follows: with whom does the duty of care lie for equipping teachers and pupils (!) with the required ergonomic working conditions? There is a short answer to this in the business world. The employer is the first point of contact. There is no real reason why this should not also be the case in schools. However, the school maintaining body and the proprietor of the educational establishment or the school building are also part of the equation. If the classroom is actually the primary and perhaps the most important tool available to the teacher, should this tool not be adapted to the job in hand? At least in the case of other ergonomic conditions (e.g. lighting) this responsibility is generally accepted by the building maintaining body. The architect is also called into question here. When designing a building and/or planning a refurbishment the architect has a influence on the work load of the teachers and – according to the results of KLATTE – on the performance potential of the pupils which must not be underestimated.

The reality is sobering. Planners and building maintaining bodies do not yet take the room acoustic properties of a school building seriously as criteria for its structural quality – even though experience shows that sensitivity has risen sharply in this area in recent years. It is nevertheless necessary to be aware of the relationships and to know to what use the rooms will be put. GOYDKE (2003) shows clear deficits in the area of the education and training of architects with regard to building and room acoustics as well as effective countermeasures.

In these times of tight purse strings, however, clear and strict specifications are the key to actually implementing better room acoustics (wherein high quality room acoustic building solutions do not necessarily cost more money than poor room acoustic solutions). The planning of school buildings is in no way moving towards a vacuum. DIN 18041 defines at least for Germany the current state of the technology. Public sector accident insurers and municipal accident insurance associations refer to room acoustics as an essential planning goal. There is as yet, however, no building supervisory introduction to room acoustic requirements for school buildings.

The thinking behind a “TOP model”, that pedagogical efforts and ergonomic framework must interact for successful teaching to take place, is by no means a new idea. BURGERSTEIN AND NETOLITZKY, then under the heading of “School hygiene”, formulated this approach as far back as 1898 – and it has lost none of its relevance in the intervening 100 years. Not least because of the fact, that throughout this time it has rarely been pursued, developed or implemented. However, one must mention the efforts of the “Bundesministeriums für Bildung and Wissenschaft” (Federal Ministry for Education and Research) to revitalise this subject in 1977 within the context of the school stress debate. The interdisciplinary research commissioned at that time into pupil stress was however never realised in the following 30 years to the extent desired. A single exception was the BAS project by BERNDT ET AL. (1982). There is as great a need now as there was then for more interdisciplinary research into schools as a workplace. For example in the present investigation the question of the

influences of the workplace ergonomics on fatigue processes have been answered only partially. Important issues to address would also include further research into the significance of the length of a lesson (single or double lesson), of the rhythm of breaks, the school day or other cycles for fatigue and/or recovery.

BURGERSTEIN AND NETOLITZKY therefore still point the way for us today above all because they succeeded for the first time – and the only time as yet - in carrying out a complete “synoptic” overview of a series of ergonomic parameters for schools. In the end, this interdisciplinary collection from the 19th century can be refined with the extended technical and methodical skills of the 20th century to take a key step in making schools fit for the 21st century.

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9 Directory of Figures

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11 Appendix

Frequency-dependent reverberation times, room volumes and number of pupil places in each of the rooms involved

Reverberation time **V m³** **Pupils**

Cl 1a	125	250	500	1k	2k	4k	8k	AV	STI	225	26
empty	0.84	0.84	0.79	0.68	0.64	0.58	0.5	**0.7**	0.7		
half	0.79	0.7	0.68	0.58	0.56	0.51	0.42	**0.6**	0.72		
occup.	0.72	0.68	0.65	0.54	0.51	0.46	0.39	**0.56**	0.73		

Cl 1b	125	250	500	1k	2k	4k	8k	AV	STI	230.2	26
empty	1	0.81	0.73	0.65	0.63	0.57	0.46	**0.69**	0.71		
half				0.61		0.61	0.67	**0.63**	0.71		
occup.				0.61	0.53	0.59	0.84	**0.64**	0.71		

Cl 2C	125	250	500	1k	2k	4k	8k	AV	STI	182.4	28
empty	1.09	0.97	0.8	0.68	0.64	0.58	0.45	**0.74**	0.7		
half	0.92	0.78	0.67	0.56	0.56	0.48	0.4	**0.62**	0.72		
occup.	0.91	0.72	0.63	0.53	0.52	0.46	0.38	**0.59**	0.73		

Cl 2D	125	250	500	1k	2k	4k	8k	AV	STI	132.8	26
empty	0.47	0.45	0.44	0.51	0.48	0.45	0.38	**0.45**	0.79		
half	0.49	0.39	0.35	0.44	0.4	0.38	0.33	**0.4**	0.8		
occup.	0.5	0.41	0.33	0.41	0.38	0.34	0.32	**0.39**	0.81		

Cl 3c	125	250	500	1k	2k	4k	8k	AV	STI	206.9	30
empty	0.83	0.71	0.67	0.6	0.59	0.64	0.39	**0.63**	0.74		
half	0.75	0.68	0.62	0.53	0.52	0.52	0.38	**0.57**	0.75		
occup.	0.7	0.66	0.59	0.52	0.5	0.45	0.32	**0.53**	0.77		

Cl 3d	125	250	500	1k	2k	4k	8k	AV	STI	221.6	24
empty	0.5	0.44	0.44	0.44	0.43	0.41	0.4	**0.44**	0.78		
half	0.46	0.39	0.4	0.41	0.4	0.37	0.37	**0.4**	0.8		
occup.	0.45	0.37	0.37	0.39	0.37	0.35	0.37	**0.38**	0.81		

Cl 4c	125	250	500	1k	2k	4k	8k	AV	STI	233.4	28
empty	0.5	0.46	0.48	0.49	0.49	0.45	0.41	**0.47**	0.76		
half	0.44	0.43	0.41	0.45	0.43	0.41	0.39	**0.42**	0.79		
occup.	0.45	0.43	0.38	0.41	0.41	0.38	0.36	**0.4**	0.8		

Cl 4d	125	250	500	1k	2k	4k	8k	AV	STI	182	26
empty	0.39	0.39	0.41	0.46	0.48	0.44	0.4	**0.42**	0.8		
half	0.37	0.37	0.36	0.4	0.43	0.4	0.37	**0.38**	0.81		
occup.	0.36	0.35	0.34	0.4	0.4	0.57	0.36	**0.4**	0.81		

Cl 2b	125	250	500	1k	2k	4k	8k	AV	STI	225.9	24
empty	0.88	0.93	0.87	0.83	0.74	0.58	0.44	**0.75**	0.68		
half	0.74	0.85	0.82	0.71	0.62	0.52	0.44	**0.67**	0.71		
occup.	0.71	0.81	0.78	0.68	0.59	0.49	0.42	**0.64**	0.71		

Cl 2bs	125	250	500	1k	2k	4k	8k	AV	STI	225.9	24
empty	0.34	0.3	0.3	0.32	0.35	0.37	0.35	**0.33**	0.86		
half	0.31	0.26	0.28	0.28	0.31	0.34	0.31	**0.3**	0.86		
occup.	0.28	0.25	0.25	0.28	0.31	0.34	0.3	**0.29**	0.87		

12 Epilog

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Gerhart Tiesler and Markus Oberdörster

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