THERMAL AND ACOUSTICAL PERFORMANCE OF "BUFFER ROOMS"

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ABSTRACT

The term "buffer room" refers in this context to spaces built between thermally, visually, and acoustically "controlled" indoor rooms and the "noncontrollable" outdoor environment. Examples of buffer rooms are sunrooms, atria, (enclosed) staircases, and air locks.

In a long-term research effort carried out in Austria, buffer rooms were studied with regard to their hygrothermal and acoustical performance within a human-ecological framework. Special attention was paid to the problems of temperature fluctuations and risk of overheating, ventilation rates, and humidity control as well as sound transmission. The research agenda included studies under controlled conditions in SHA, a facility dedicated to building physics research in Vienna, Austria, as well as field investigations.

This paper gives a summarized overview of the content and results of some of these studies, focusing on the issues of thermal performance as well as the acoustical insulation effect of sunrooms and its relationship to natural ventilation.

BACKGROUND

Since 1987, the Division for Building Physics and Human Ecology of a university in Vienna, Austria, has initiated a number of studies with regard to the thermal and acoustical performance of buffer spaces (Haider et al. 1991; Mahdavi 1989). The majority of these studies were conducted in a research facility in Vienna, Austria, which includes four residential units that are dedicated to building physics studies under "realistic" settings (Figure 1). The building is equipped with a weather station, comprehensive data sensing and processing capabilities, experimental envelope constructions, as well as different conventional and "alternative" HVAC systems. The residential units in the facility have been particularly appropriate for the study of hygrothermal and acoustical behavior of buffer spaces due to the existence of sunrooms adjacent to indoor rooms.

AN INTEGRATIVE HUMAN ECOLOGICAL APPROACH

An important aspect of buffer room studies is the underlying integrative approach formulated within the conceptual framework of human ecology (Knötig 1990; Mahdavi 1993). This approach emphasizes the importance of considering not only the "material-energetic" aspect but also the "informatory" aspect of the performance of buffer spaces (Table 1). In the human ecological terminology, each "environmental relation" has a material-energetic as well as an informatory aspect.

- A quantity of matter/energy is the precondition of any descriptive approach. Material-energetic aspect refers to this "existential" aspect of all entities.
- Matter and energy quantities are given in some statistically nonuniform distribution that can be described in terms of a structure to which an *information* content can be allocated. This "structural" aspect can be understood as the informatory aspect.

In practice, the matter-energy aspect is considered more commonly, perhaps because it can be quantified conveniently. However, it should be emphasized here that these two aspects are complementary and must be taken into consideration for an integrative evaluation of the performance of buffer spaces.

ACOUSTICAL ASPECTS

Buffer rooms can be seen from two acoustically relevant points of view; first in terms of the acoustical environment within the buffer space (sound distribution, reverberant field, ambient noise levels) and, second, in terms of their sound-insulating effect on the adjacent indoor rooms. In this contribution only the latter aspect is addressed, with discussion of the results of an empirical study of the sound transmission through a sunroom.

It is important to understand that the acoustical buffer effect of sunrooms should not be propagated as the general solution to the problem of traffic noise annoyance. The adequate noise control strategies are principally source-oriented (Mahdavi 1986, 1992). However, sunrooms provide additional means for acoustical control and may alleviate, to a certain degree, extremely problematic situations.

Construction

Measurements were taken in one of four sunrooms (Figure 2). A few control measurements were also carried

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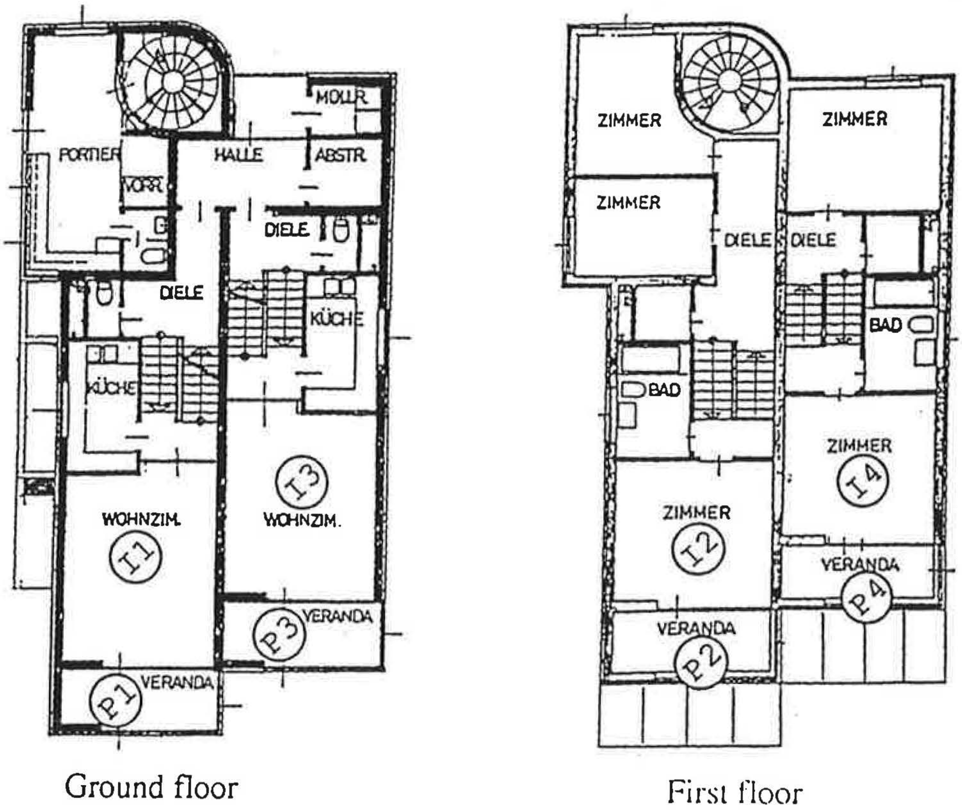


Figure 1 *Schematic illustration of ground floor and first floor of research facility.*

TABLE 1
Summarized Overview of Major "Material-Energetic" and "Informatory" Considerations in the Evaluation of the Performance of Buffer Spaces

Material-energetic aspect	Informational aspect
• Reduced energy consumption while maintaining the effectiveness of the temperature regulation in indoor spaces;	• Counteracting indoor climate "monotony";
• Improved sound insulation for indoor spaces;	• Better "transition" from inside to outside (and vise versa) through providing a possibility for preparation/adaptation;
• Better indoor air quality control without compromising the thermal and acoustical buffer effect;	• Improved possibilities for inhabitants to have control on their living conditions;
• Better performance of buffer spaces through integrative thermal, acoustical and visual design;	• Providing "direct" contact with environmental factors while responding to privacy needs;
• Increased duration of possible occupation of buffer spaces.	• "Symbol" functions.

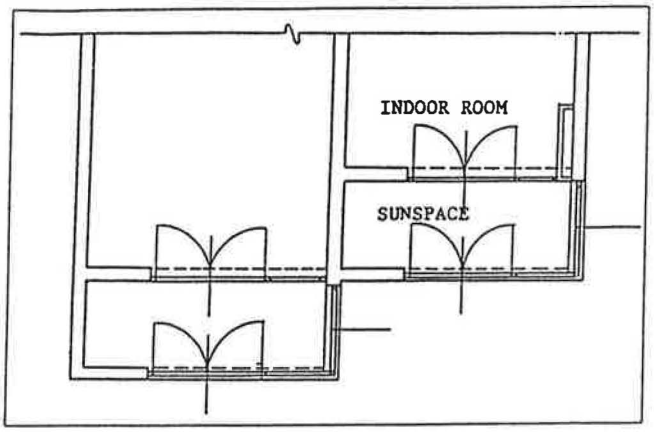


Figure 2 *Schematic plan of sunroom and adjacent living room.*

out in other sunrooms of to examine the reproducibility of the results.

The transparent part of the external sunroom envelope and the partition wall between the sunroom and living room consists of double-glazed units (12 mm air gap) with timber frame.

Elements and Configurations

Table 2 shows the different positions of the operable parts of the sunroom envelope considered for the measurements. The corresponding data for the glazed door in the partition wall between sunroom and living room are identical with the door in the sunroom envelope.

Measurement Method

The "open-closed method" was chosen for the measurements. This method can be applied in all cases where the test object is operable (ÖNORM 1987). Using a properly located external sound source (speaker system) the standardized sound level difference ($D_{n,T,OG}$), can be determined according to the following equation:

$$D_{n,T,OG} = L_O - L_G + 10 \cdot \log (T_G \cdot T_O^{-1}) \tag{1}$$

where

$D_{n,T,OG}$ = standardized sound level difference, dB;
L_O = mean sound pressure level in receiver room with open test object, dB;
L_G = mean sound pressure level in receiver room with closed test object, dB;
T_O = reverberation time in receiver room with open test object, s;
T_G = reverberation time in receiver room with closed test object, s.

To maintain a certain degree of repeatability, it is required that the maximum deviation range within the sound pressure field in front of the test object does not exceed 5 dB. Preparatory studies were undertaken in a university's anechoic chamber to study the sound pressure distribution in front of a test object using the same measurement configuration as in the research facility measurements. Examples of the results are shown in Figure 3. The standard deviation of the measured sound pressure levels in front of a test object was found to be 1.7 dB at 500 Hz, 1.5 dB at 1000 Hz, and 1.8 dB at 2000 Hz. The absolute deviation range for all these three frequencies did not exceed 5 dB.

Measurement Program

The measurements were carried out for various positions of the operable parts of sunroom envelope and partition wall (between sunroom and indoor room). A

TABLE 2
Operable Elements of the Sunroom Envelope and Their Positions

Element	Position	Remarks
Clerestory	Closed	-
	Slot open	Slot width: 1 ... 2 mm; slot depth: 110 mm; slot length: 2.7 m
	Max. tilt	geometrical leakage area: 0.08 m2
Window	closed	-
	Open pos.1	geometrical leakage area: 0.05 m2
	Open pos.2	geometrical leakage area: 0.14 m2
	Open	geometrical leakage area: 1.26 m2
Door	Closed	-
	Slot open	Slot width: 1 ... 2 mm; slot depth: 110 mm; slot length: 2 m; geometrical leakage area: 0.003 m2
	Open pos.1	geometrical leakage area: 0.06 m2
	Open	geometrical leakage area: 1.61 m2

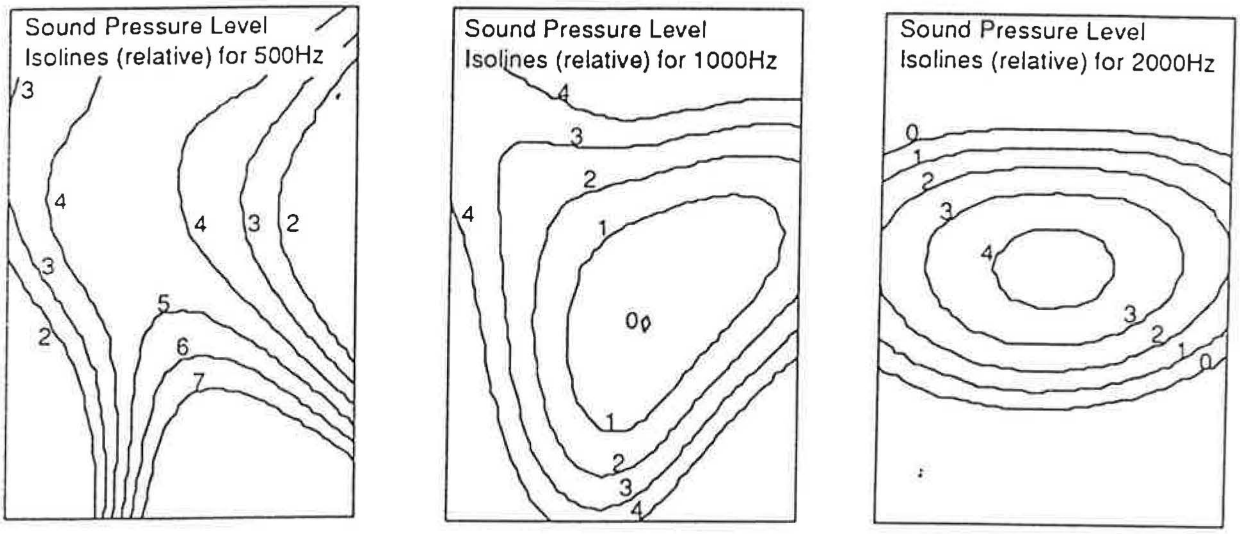


Figure 3 *Sound pressure distribution (relative illustration) in front of a door element measured in an anechoic chamber (for 500, 1000, and 2000 Hz).*

summarized overview of these configurations is given in Table 3.

A separate measurement of the sound insulation of the sunroom envelope and partition wall was performed. This provided data for a comparison of the result derived by arithmetical summation of the insulation of the two components with the measured values of their combined effects, i.e., the overall sound insulation effect of the sunroom.

Results

The measured frequency-dependent standardized sound level difference values ($D_{n,T,OG}$) are graphically illustrated in Figures 4 to 6. The information on the position of operable elements is included in the description of each curve. The codes given in parenthesis refer to Table 3. The corresponding weighted standardized sound level difference values ($D_{n,T,w,OG}$) are given for each curve (in brackets) and summarized in Figure 7. These weighted values are derived by comparison of actual test results, obtained for a series of sixteen 1/3-octave bands, to a reference curve according to a fixed procedure (ISO 1976; ÖNORM 1990). This procedure is comparable to (though not identical to) the procedure for derivation of STC values.

Figures 4a to 4c show frequency-dependent standardized sound level differences associated with the sunroom

TABLE 3
Measurement Program (Operable Sunroom Components and Their Positions

		Sunroom envelope			Partition wall
Test Object	Code	Clerestory	Window	Door	Door
Sunroom envelope	A1	Closed	Closed	Closed	-
	A2	Slot	Closed	Closed	-
	A3	Closed	Closed	Slot	-
	A4	Closed	Open pos.1	Closed	-
	A5	Closed	Open pos.2	Closed	-
	A6	Closed	Closed	Open pos.1	-
	A7	Max. tilt	Closed	Closed	-
	A8	Max. tilt	Open pos.2	Closed	-
	A9	Max. tilt	Closed	Open pos.1	-
Partition wall between sunroom and indoor room	B1	Max. tilt	Open	Open	Closed
	B2	Max. tilt	Open	Open	Slot
	B3	Max. tilt	Open	Open	Open pos.1
Sunroom envelope and partition wall	C1	Closed	Closed	Closed	Closed
	C2	Slot	Closed	Closed	Slot
	C3	Closed	Open pos.1	Closed	Closed
	C4	Max. tilt	Closed	Closed	Closed
	C5	Max. tilt	Closed	Closed	Slot
	C6	Max. tilt	Closed	Open pos.1	Closed
	C7	Max. tilt	Closed	Open pos.1	Open pos.1

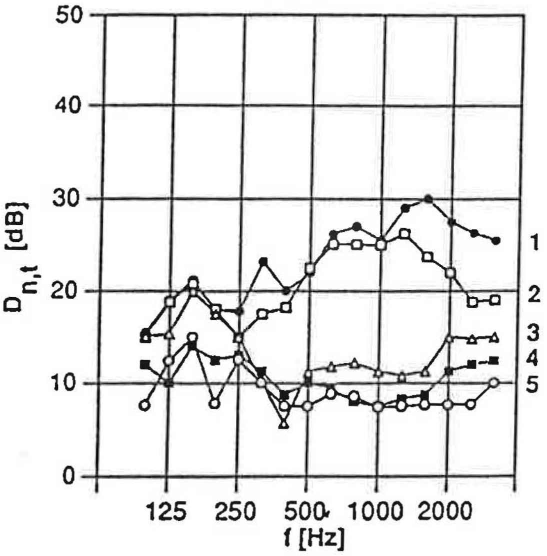


Figure 4a *Sound level difference (sunroom envelope)*
1: fully closed (A1), [26 dB]
2: clerestory/slot (A2), [22 dB]
3: clerestory/maximum tilt (A.7), [12]
4: clerestory/maximum tilt + window/ open position 2 (A8), [10 dB]
5: clerestory/maximum tilt + door/open position 1 (A9), [8 dB]

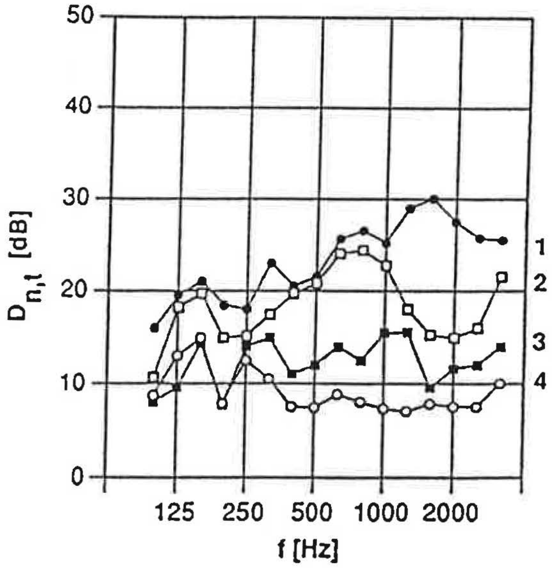


Figure 4b *Sound level difference (sunroom envelope)*
1: fully closed (A1), [26 dB]
2: door/slot (A3), [19 dB]
3: door/open position 1 (A.6),[13B]
4: clerestory/maximum tilt + door/open position 1 (A9), [8 dB]

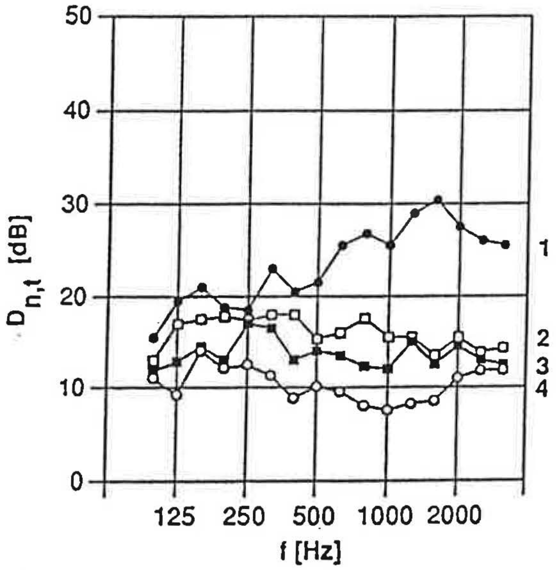


Figure 4c *Sound level difference (sunroom envelope)*
1: fully closed (A1), [26 dB]
2: window/open position 1 (A4), [15 dB]
3: window/open position 2 (A5), [14 dB]
4: clerestory/maximum tilt + window/ open position 2 (A8), [10 dB]

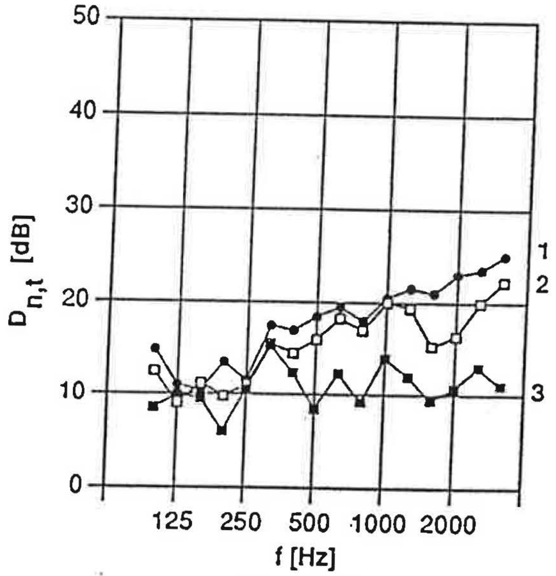


Figure 5 *Sound level difference (partition wall)*
1: door closed (B1), [20 dB]
2: door/slot (B2), [18 dB]
3: door/open position 1 (B3), [11 dB]

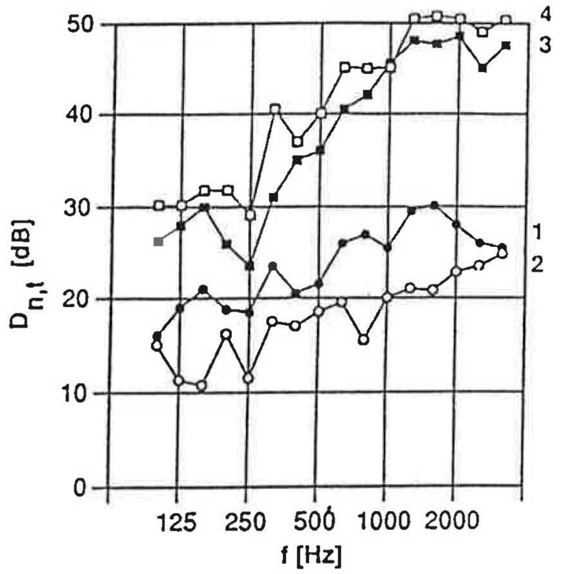


Figure 6a — *Sound level difference (sunroom)*
1: envelope: fully closed (A1), [26 dB]
2: partition wall: closed (B1), $D_{n,t,w,}$OG *= 20 dB*
3: sunroom (measured: C1), $D_{n,t,w,}$OG *= 40 dB*
4: sunroom (calculated), $D_{n,t,w,}$OG *= 45 dB*

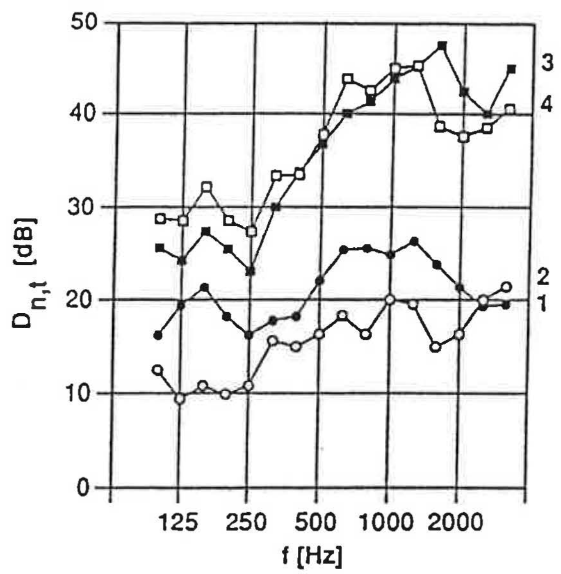


Figure 6b — *Sound level difference (sunroom)*
1: envelope: clerestory/slot (A2), [22 dB]
2: partition wall: door/slot (B2), [18 dB]
3: sunroom (measured: C2), [39 dB]
4: sunroom (calculated), [39 dB]

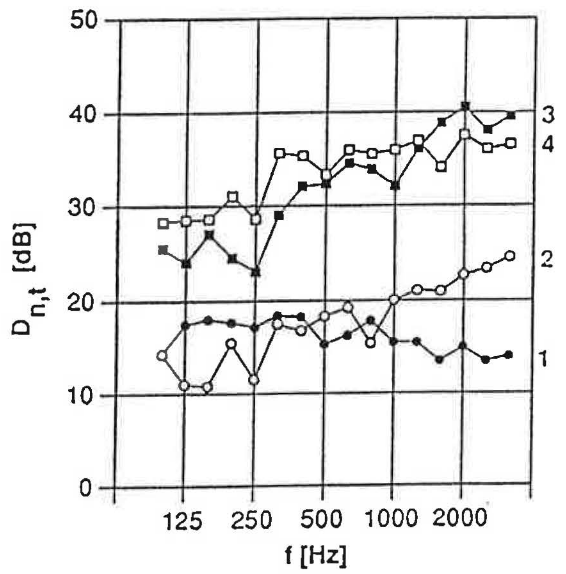


Figure 6c — *Sound level difference (sunroom)*
1: envelope: window/open position 1 (A4), [15 dB]
2: partition wall: closed (B1), [20 dB]
3: sunroom (measured: C3), [35 dB]
4: sunroom (calculated), [36 dB]

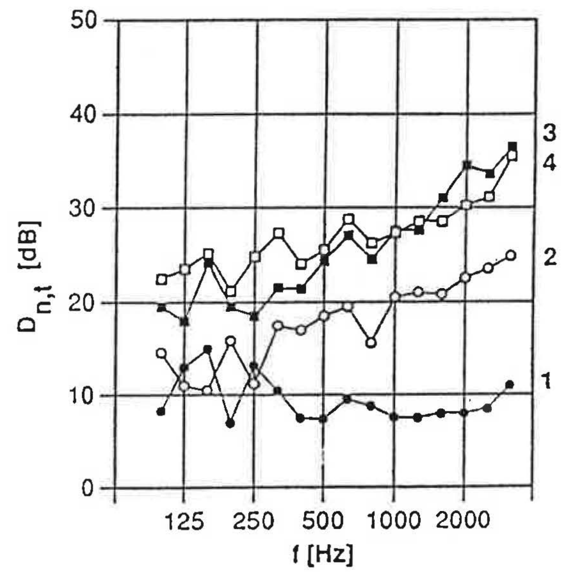


Figure 6d — *Sound level difference (sunroom)*
1: envelope: clerestory/max.tilt + door/open position 1 (A9), [8 dB]
2: partition wall: closed (B1), [20 dB]
3: sunroom (measured: C6), [28 dB]
4: sunroom (calculated), [29 dB]

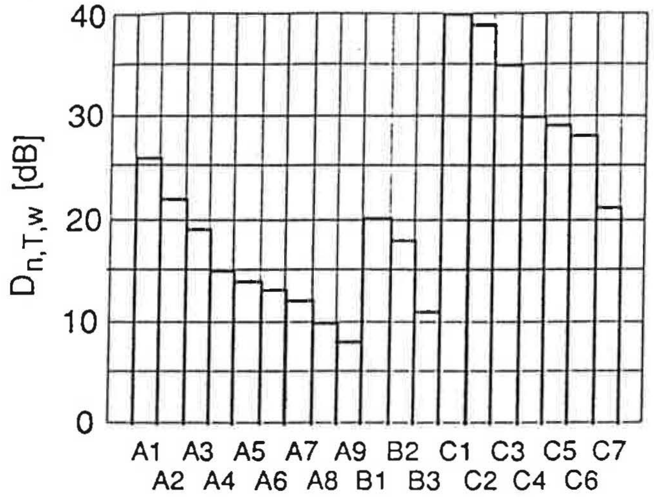


Figure 7 *Weighted standardized sound level differences due to the sunroom as a function of the position of operable elements (codes refer to Table 3)*

envelope (receiver room: sunroom). Figure 5 shows the frequency-dependent standardized sound level differences associated with the partition wall between the sunroom and indoor room (receiver room: indoor room, all operable elements of the sunroom envelope open). Figures 6a to 6d show the measured values for the combined effect of sunroom envelope and partition wall, as well as separate insulation values for each component. For comparison purposes, the arithmetic summation of the measured insulation values of sunroom envelope and partition wall are also included in these diagrams.

Interpretation

Impact of the Resonance Frequency The graphic illustration of the results demonstrates a clear break in the sound insulation curves of both sunroom envelope and partition wall at a frequency of about 250 Hz. This can be explained, as the following estimation demonstrates, through the resonance effect of the double-glazing system (2 x 4-mm glazing, 12 mm distance). The resonance frequency of the system (fr) is generally given by

$$f_r = 160 \cdot [s' \cdot (m_1^{-1} + m_2^{-1})]^{0.5} \tag{2}$$

where

f_r = resonance frequency, Hz;
s' = dynamic stiffness of the "spring," $MN \cdot m^{-3}$ ($lbf \cdot ft^{-3}$);
m_1, m_2 = surface densities of the layers, $kg \cdot m^{-2}$ ($lb \cdot ft^{-2}$).

Given the distance between glass panes, its dynamic stiffness can be approximated using the following equation:

$$s'_L = 0.14 \cdot d^{-1} \tag{3}$$

where

s'_L = dynamic stiffness of the gap between glass panes, $MN \cdot m^{-3}$ ($lbf \cdot ft^{-3}$);
d = distance between glass panes, m (ft).

Assuming a glass density of 2300 $kg \cdot m^{-3}$, the resonance frequency of the glazing system can be calculated according to the following procedure:

$$m^1 = m^2 = 0.004 \cdot 2300 = 9.2\ kg \cdot m^{-2}.$$

Using Equation 3;

$$s'_L = 0.14 \cdot 0.012^{-1} = 11.67\ MN \cdot m^{-3}.$$

Using Equation 2;

$$f_r = 160 \cdot [11.67 \cdot (9.2^{-1} + 9.2^{-1})]^{0.5} \cong 255\ Hz.$$

Impact of the Resonance Frequency The graphic illustration of the results demonstrates a clear break in the sound insulation curves of both sunroom envelope and partition wall at a frequency of about 250 Hz. This can be explained, as the following estimation demonstrates, through the resonance effect of the double-glazing system (2 x 4-mm glazing, 12 mm distance). The resonance frequency of the system (fr) is generally given by

- The sound insulation of the sunroom envelope decreases 4 dB by transition from closed position of clerestory to slot position. However, by transition to the next opening position (maximum tilt position), the sound insulation decreases (compared to the closed position) 14 dB. Thus, the transition from slot position to tilt position of the clerestory results in a 10 dB decrease in the sound insulation of the sunroom envelope.
- A similar analysis of the partition wall (between sunroom and indoor room) shows that its insulation decreases 2 dB by bringing the door from the closed position to the slot position. However, by transition to open position 1, the sound insulation decreases 9dB (compared with the closed position). Thus, the transition from slot position to open position 1 is accompanied with a 7 dB decrease of sound insulation.
- The study of the sunroom "system" (combined effect of both sunroom envelope and partition wall) shows that, compared to the closed position, its insulation decreases only 1 dB if the clerestory (in sunroom envelope) and the door (inpartition wall) are in the slot position. However, the soundinsulation decreases 15 dB if these two elements are brought to the maximum tilt

position and open position 1 respectively. Thus, the sound insulation effect of the sunroom decreases 14 dB by transition from the slot position to the next practical ventilation position.

The analysis of the measurement results reveals further that the buffer room can provide various ventilation configurations while achieving an effective sound insulation that is higher than the sound insulation of its individual components (sunroom envelope or partition wall) even in the closed position (Figure 7). For example, the sound insulation of the sunroom system, even with clerestory (in the sunroom envelope) and the door (in partition wall) in slot position, is significantly higher that the closed sunroom envelope. Also, the sound insulation of the sunroom system with clerestory and door (in sunroom envelope) in maximum tilt position and both doors (in envelope and partition wall) in open position 1 is higher than the sound insulation of the closed sunroom envelope.

Comparison of Calculations and Measurements For estimation purposes, it is of interest to know the degree of correlation between the measured sound insulation of the sunroom "system" and the summation of the measured values of its components (sunroom envelope, partition wall). As the graphical illustration of the results indicates (see Figures 6a to 6d) there is good agreement between the measured values of the sunroom system and the arithmetical sum of measurement results for its components (particularly in the medium- and high-frequency range). According to a statistical analysis, in the case of the sunroom studied here, the following relationship can be formulated:

$$D_{n,T,w,S} = D_{n,T,w,E} + D_{n,T,w,P} - 1 \quad (4)$$

where

$D_{n,T,w,S}$ = weighted standardized sound level difference due to the sunroom system, dB;

$D_{n,T,w,E}$ = weighted standardized sound level difference due to sunroom envelope, dB;

$D_{n,T,w,P}$ = weighted standardized sound level difference due to partition wall, dB.

Sound Insulation and Ventilation

Parallel to acoustical studies, measurements of fresh air volume flow in the indoor room were carried out for a number of configurations of operable sunroom components. During these measurements, average wind velocities of 1 to 4.4 $m \cdot s^{-1}$ and average air temperature differences (between outdoor space and indoor room) of 14.3 to 21.5 K were prevailing. Although sets of acoustical and airflow measurements were available only for a few ventilation configurations, a correlation analysis was performed. The full line in Figure 8 illustrates the result of the regression analysis of the relationship between sound insulation and fresh air volume flow. For comparison purposes, the result of an older study (Lang 1962) is also illustrated (the dashed line in Figure 8) in which the air permeability and the sound insulation of windows were compared in a laboratory setting. Based on this figure and assuming a 2 dB sound insulation reduction due to flanking transmission, a total insulation improvement of approximately 5 dB can be attributed to this sunroom.

THERMAL ASPECTS

Long-Term Measurements

In four sunrooms, long-term measurements have been undertaken, capturing outdoor air temperature, outdoor relative humidity, wind velocity, global radiation, radiation incident on three vertical facades, as well as air temperatures in sunrooms and indoor rooms. In addition, the tracer-gas method was used to measure the air volume flows between the buffer room/indoor room, buffer room/outdoor space, and indoor room/outdoor space (Haider et al. 1991). The position of the door in the partition wall between the sunroom and indoor room was kept constant throughout the measurements (door in open position 1). However, several positions of clerestory in sunroom envelope were considered. The results of these measurements were used to study the relationships between different parameters such as air volume flow and temperature difference (Figures 9a and 9b).

Studies with Model of Human Body

To study the indoor climate pattern and the related thermal comfort issues in sunrooms, measurements were carried out (in both winter and summer) utilizing a 1:1 model of the human body. Registered data included total heat

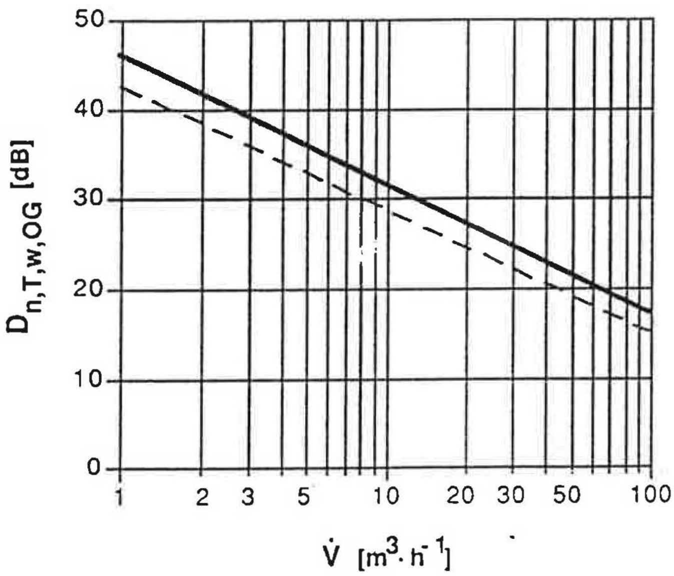


Figure 8 *Correlation between the sound insulation of the sunroom and the fresh air volume flow in indoor room (full line).*

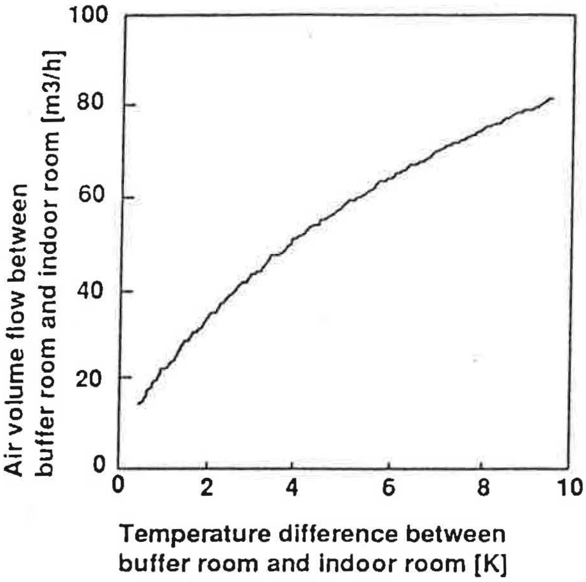


Figure 9a *Air volume flow between sunroom and indoor room as function of temperature difference.*

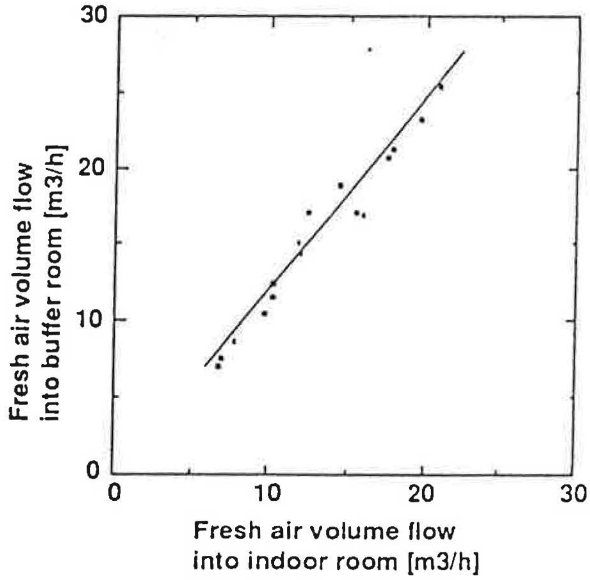


Figure 9b *Air volume flow in indoor room as a function of the fresh airflow into the sunroom.*

emission rates, heat emission rates from the surfaces of different body parts, "surface reference temperatures," as well as the relevant parameters of indoor climate. The measurements were repeated for five different orientations of the mannequin (assuming the mannequin's position with a view normal to sunroom glazing to be 0°, the other positions were 90°, 180°, 225°, and 270°). Example of results are shown graphically in Figures 10a and 10b. The primary outcome of the results of the studies can be summarized in the following manner:

- The heat losses of individual body parts (clothed or nonclothed) can be measured effectively and used in terms of indicators of local exchange processes.
- The measurable heat losses of the mannequin allow for reasonable evaluation of thermal comfort conditions for human beings under similar thermal conditions.
- Given winter solar radiation, acceptable thermal conditions can be expected in sunrooms at low outdoor temperatures. During sunny periods, thermally acceptable occupational conditions are maintained in the research facility's sunrooms (without heating) between 9:00 a.m. and 5:00 p.m.
- Under summer conditions, the overheating risk is high if no shading is provided and the air change rate is low.
- Under summer conditions, thermally acceptable occupational conditions can be maintained in the sunrooms provided shading and cross-ventilation are available.

Simulation Studies

Theoretical Background Parallel to empirical studies, a simulation program was developed to study the complex thermal behavior of buffer spaces. Since the program was meant to be used specifically for general parametric analysis purposes, the solution of heat balance equations is not performed in the time domain but in the domain of Fourier coefficients (eight harmonics are processed). Aspects of background theory and some related terminological and procedural information are given in Haferland and Heindel (1975), Haferland et al. (1975), Heindel and Koch (1976), and Koch and Pechinger (1977).

Multi-Criteria Parametric Studies Based on simulation studies, a comprehensive set of tables was generated as a practical design support tool demonstrating the thermal behavior of certain types of sunrooms as a function of glazing type, building geometry, ventilation rates and schedule, and shading devices, as well as insulation and thermal capacitance of building components involved. The simulation studies were carried out for three typical weather situations (cloudy winter days, sunny winter days, sunny summer days). As an example, Table 4 shows simulated minimum, average, and maximum air temperatures in sunrooms for sunny winter days as a function of air change rate, thermal insulation properties of opaque and transparent elements, and shading.

Impact of Orientation A second group of simulation studies dealt mainly with the impact of orientation on the thermal performance of buffer spaces under summer conditions (15 July, outdoor temperature range = 18°C to 30°C). A room cell (concrete floor, brick walls) with an adjacent sunroom (concrete walls, insulated sill, three windows each 2.04 m^2 with double glazing) was selected for simulations which were performed for eight orientations (see Figure 11) with different air changes (2 to 20 h^{-1}) and radiation transmission factors (z = 1 to 0.27). Radiation transmission factor z denotes here the reduction of total

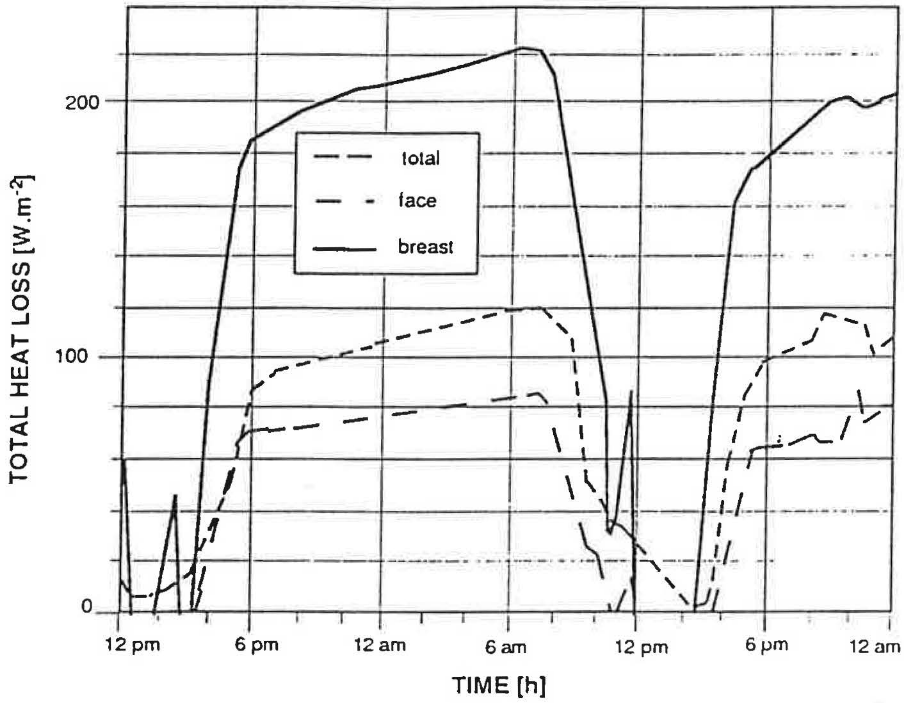


Figure 10a *Total heat loss and heat losses from face and breast of the mannequin (clo-value 0.8) in the sunroom (measurement days: January 30 and 31).*

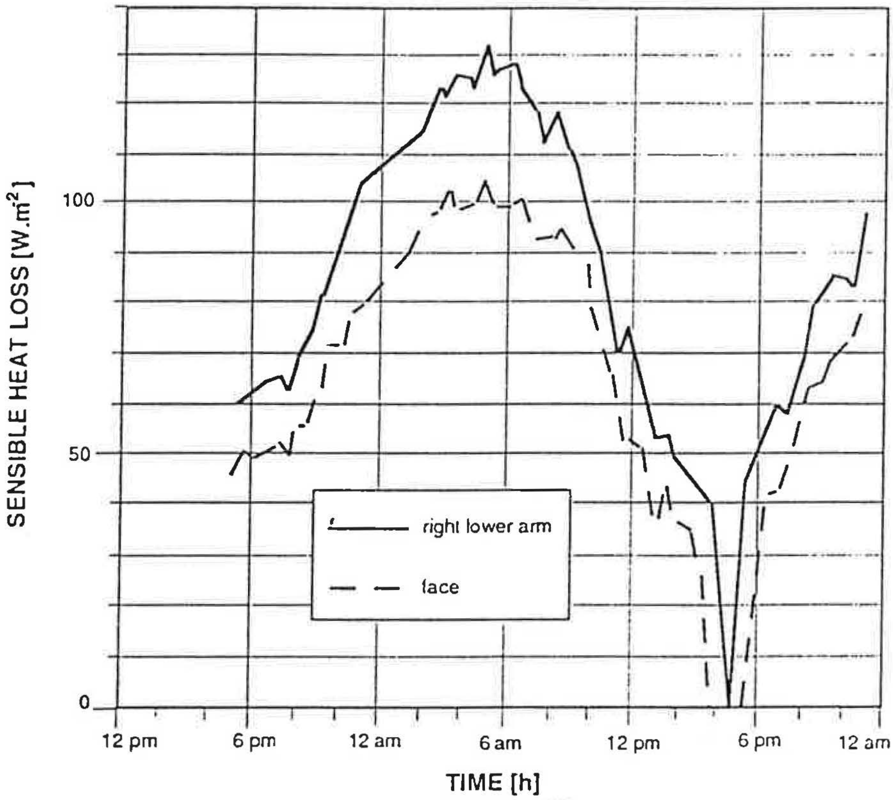
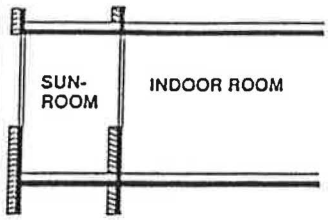
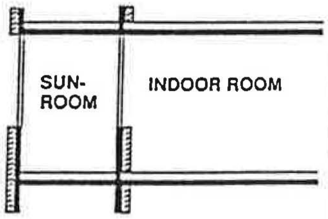
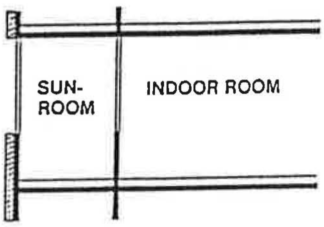
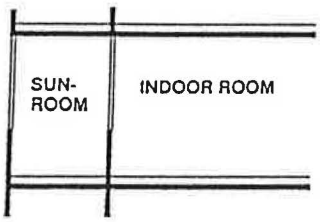
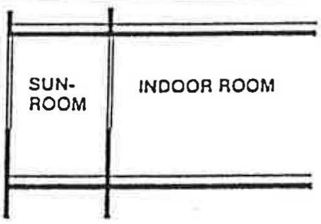


Figure 10b *Heat loss from face and right lower arm of the mannequin (clo-value 0.6) in the sunroom (measurement days: July 22 and 23).*

TABLE 4
Simulated Air Temperatures in Sunrooms for Sunny Winter Days

SUNNY WINTER DAYS			AC	Sunroom air temperature [°C]		
Sketch	External wall	Partition wall	[h^{-1}]	min.	mean	max.
	Parapet externally	Parapet externally	1.5	14.1	17.6	22.8
	insulated.	insulated.	2.0	13.2	16.8	21.9
	Double glazing.	Triple glazing.	2.5	12.4	16.0	21.1
	No shades.	No shades.	3.0	11.7	15.2	20.3
	Parapet externally	Parapet internally	1.5	14.1	17.5	22.4
	insulated.	insulated.	2.0	13.2	16.6	21.6
	Double glazing.	Triple glazing.	2.5	12.5	15.9	20.8
	No shades.	No shades.	3.0	11.8	15.2	20.1
	Parapet externally	Parapet not	1.5	14.4	17.6	22.4
	insulated.	insulated.	2.0	13.5	16.8	21.5
	Double glazing.	Double glazing.	2.5	12.7	16.0	20.7
	No shades.	No shades.	3.0	12.0	15.2	19.9
	Parapet not insulated. Double glazing. No shades.	Parapet not insulated. Double glazing. No shades.	2.0	9.0	13.2	18.8
	Parapet not insulated. Single glazing. No shades.	Parapet not insulated. Double glazing. No shades.	2.0	7.7	12.0	17.6

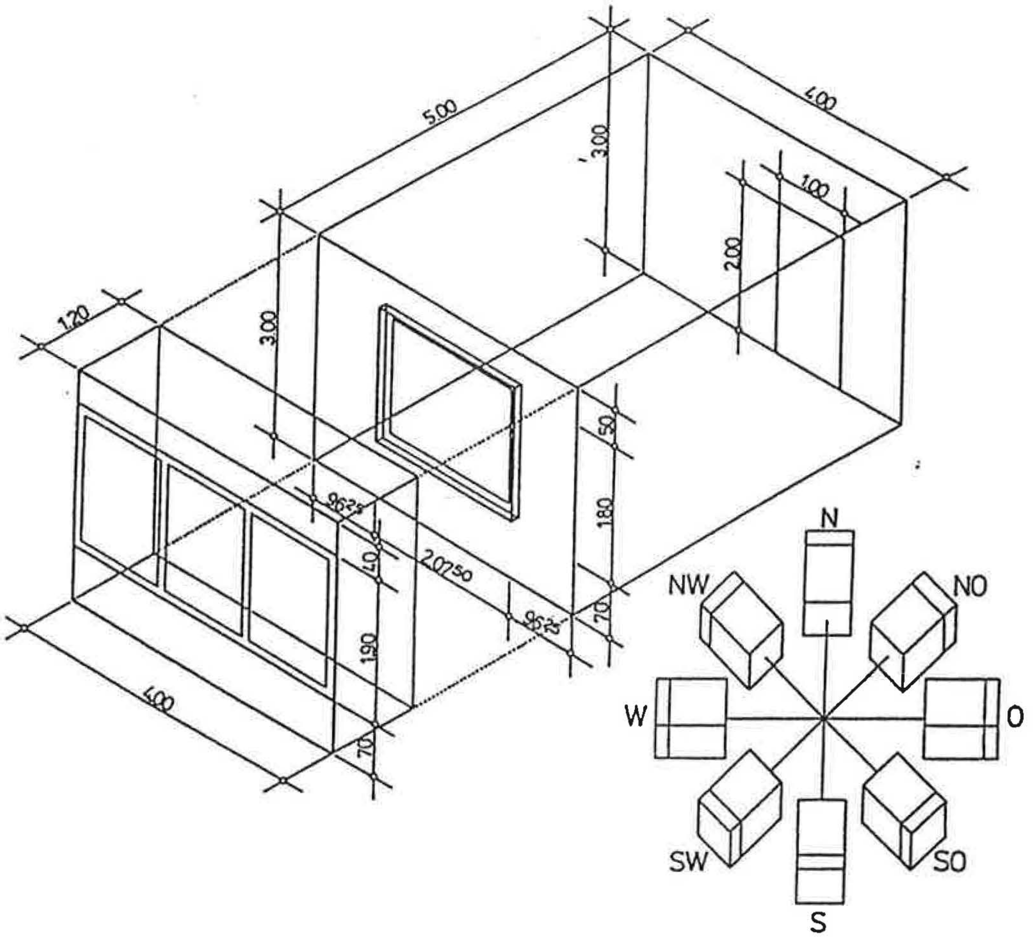


Figure 11 *Illustration of the simulation object and orientations.*

solar energy transmission through transparent building components due to shading devices (z = 1 means no shading, z = 0 means total shading). Examples of simulation results are given in Figures 12a to 12c.

SUMMARY

In a long-term research effort, buffer spaces (particularly sunrooms) were studied with regard to their hygrothermal and acoustical performance within a human-ecological framework. The majority of these studies were conducted in a research facility in Vienna, Austria, dedicated to investigations in building physics.

Sunrooms were studied in terms of their sound insulating effect on the adjacent indoor rooms. Different positions of the operable parts of the sunroom envelope were considered for the measurements, utilizing the "open-closed method." The impact of resonance effect on the sound insulation of the double-glazing system was illustrated. It was shown that due to the buffer space effect, various ventilation configurations can be realized by which the total sound insulation of the sunroom "system" is higher than the sound insulation of its individual components. A high correlation was found between the measured insulation values of the sunroom "system" and the arithmetical sum of measurement results for its components. A regression analysis was performed, indicating the correlation between the sound insulation of the sunroom system and the fresh air volume flow into the indoor room.

In four sunrooms, long-term measurements were undertaken, capturing the relationships between different parameters such as air volume flow (in the buffer room and in the indoor room) and temperature. Indoor climate patterns and the related thermal comfort issues in sunrooms were also studied, utilizing a 1:1-model of the human body. Based on the results, the thermally relevant habitability of sunrooms was evaluated for various boundary conditions as well as different mannequin positions and clothing.

A simulation program was developed to study the complex thermal behavior of buffer spaces, solving heat balance equations in the domain of Fourier coefficients. Comprehensive sets of tables were generated as a practical design support tool demonstrating the thermal behavior of certain types of sunrooms as a function of glazing type, building geometry, ventilation rates and schedule, and shading devices, as well as insulation and thermal capaci-

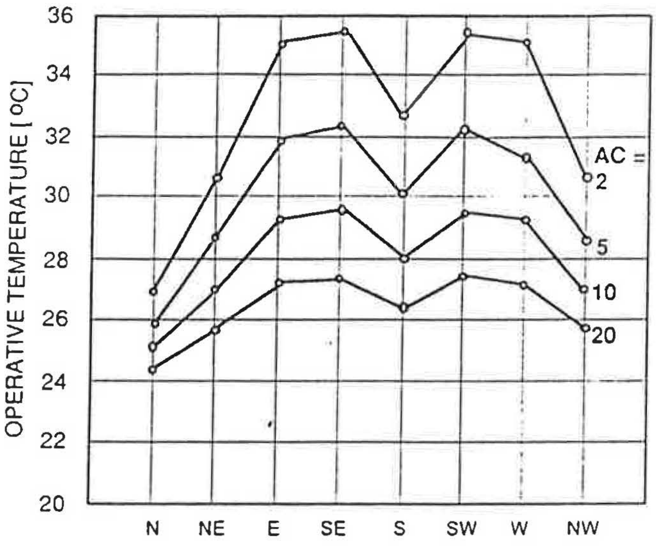


Figure 12a *Average operative temperatures in a sunroom as a function of orientation and air change (z = 1).*

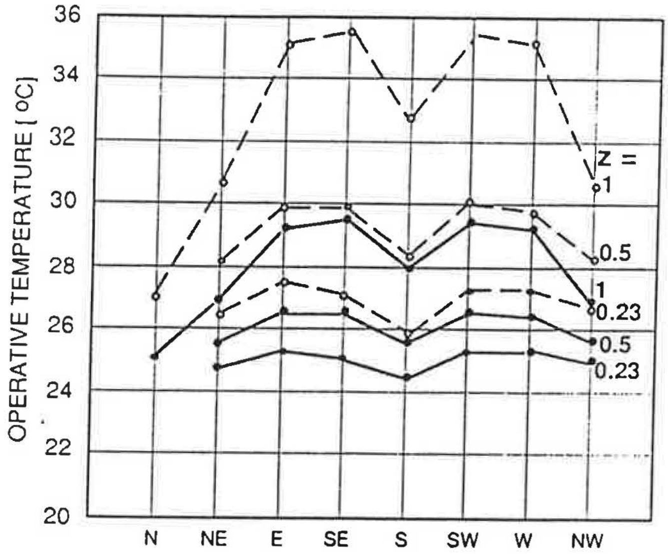


Figure 12b *Average operative temperatures in a sunroom as a function of orientation, shading and air change (full line: AC = $10\ h^{-1}$, dashed line: AC = $2\ h^{-1}$).*

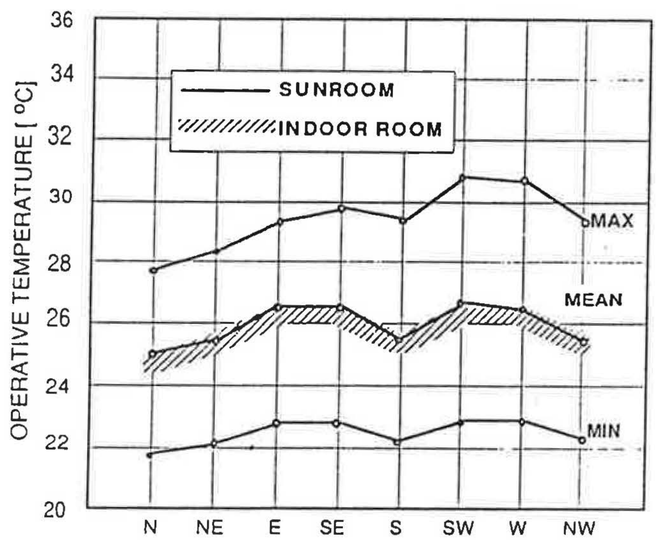


Figure 12c *Maximum, average and minimum operative temperatures in a sunroom as a function of orientation with AC = $10\ h^{-1}$, and z = 0.5 (The shaded area represents the temperature range in the indoor room adjacent to sunroom.)*

tance of involved building components. Additional simulation studies dealt mainly with the impact of orientation on the thermal performance of buffer spaces under summer conditions.

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The research described in this paper was initiated by Erich Panzhauser, the director of the Division for Building Physics and Human Ecology, Institute for Building Construction, Technical University of Vienna, Austria. The majority of the studies were carried out at SHA, Sonnehaus Arsenal, in Vienna.

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