OPAC309

Architectural Acoustic

Instructure:

Prof. Dr. Eser OLĞAR

Optical and Acoustical Engineering Department

Course arrangements

Schedule

- **Lectures(3 hours) in hall S6, main themes:**

- Introduction, basic concepts of acoustics
- Sound absorption: materials and construction
- Room acoustics
- Airborne sound insulation
- Impact sound insulation
- HVAC noise control, vibration isolation
- Acoustic design of rooms

- 1st Midterm Exam: ……**350 Point**
- Design project: …… **100 Point**
- KS Project ……**100 Point**
- Attendance……**50 Point**
- Quizes…… **200 Point**
- Final Exam: ……**600 Point (1400, Grade>450=DD)**

Schedule

- Week1- Introduction, basic concepts of acoustics
- Week2- Introduction, basic concepts of acoustics
- Week3- Sound absorption: materials and construction
- Week4 - Room acoustics
- Week5 - Room acoustics
- Week6 - Airborne sound insulation
- Week7 - 1st Midterm Exam
- Week8 – Airborne sound insulation
- Week9 - Impact sound insulation
- Week10 - HVAC noise control, vibration isolation
- Week11 - Acoustic design of rooms
- Week12 - KS Project
- Week13 - KS Project
- Week14 – Project Presentation

Execution

- **Compulsory:**

–Design project

–Exam

- **Recommended and desirable:**

–Attending lectures, 70 %

–Solving exercies independently at home

- **Course books:**

1. Environmental and Architectural Acoustics, Second edition, Z. Maekawa, J. H. Rindel and P. Lord

2. Architectural Acoustics, Second Edition,Marshall Long.

3. Any Architectural Acoustics books.

Lecture Notes: On GAUZEM webpage

Password: feryalozel (Inspired form Feryal Özel, 2022)

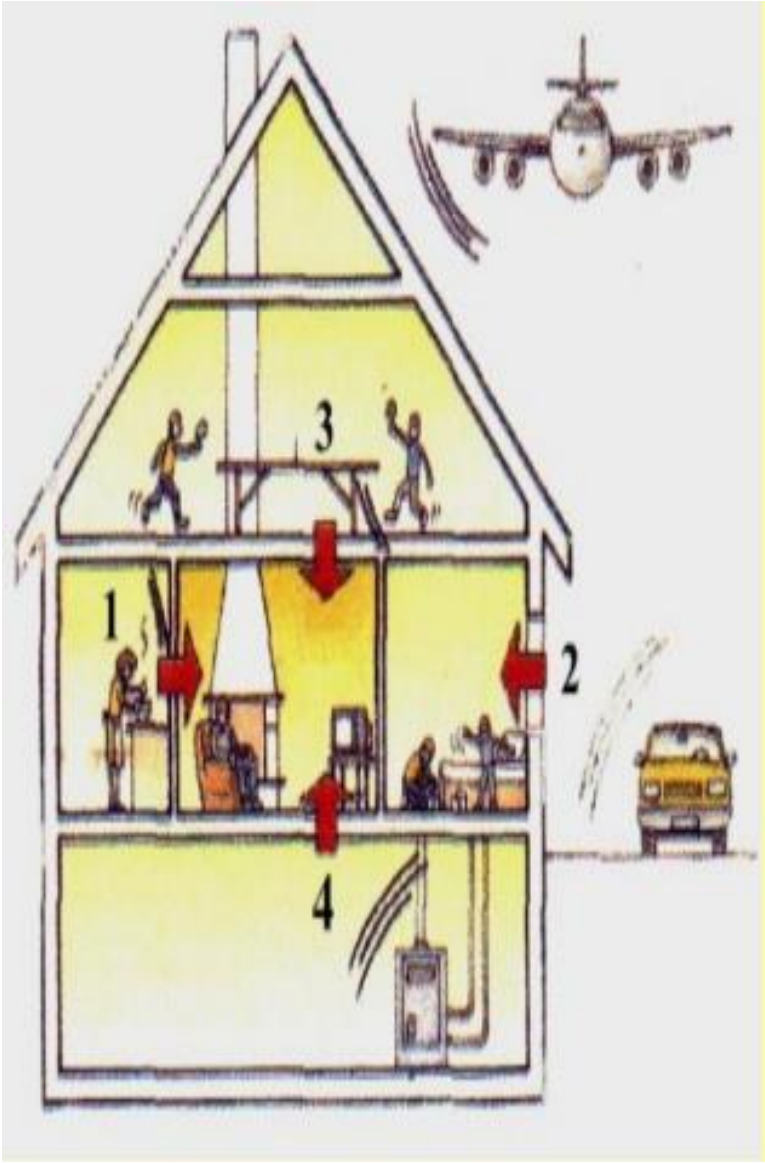
What is acoustics?

What is Acoustics?

Acoustics is the study of the generation, propagation, absorption, and reflection of sound pressure waves in a fluid medium.

Applications for acoustics include the following:

- Sonar - the acoustic counterpart of radar
- Design of concert halls, where an even distribution of sound pressure is desired
- Noise minimization in machine shops
- Noise cancellation in automobiles
- Underwater acoustics
- Design of speakers, speaker housings, acoustic filters, mufflers, and many other similar devices.
- Geophysical exploration



División of acoustics.

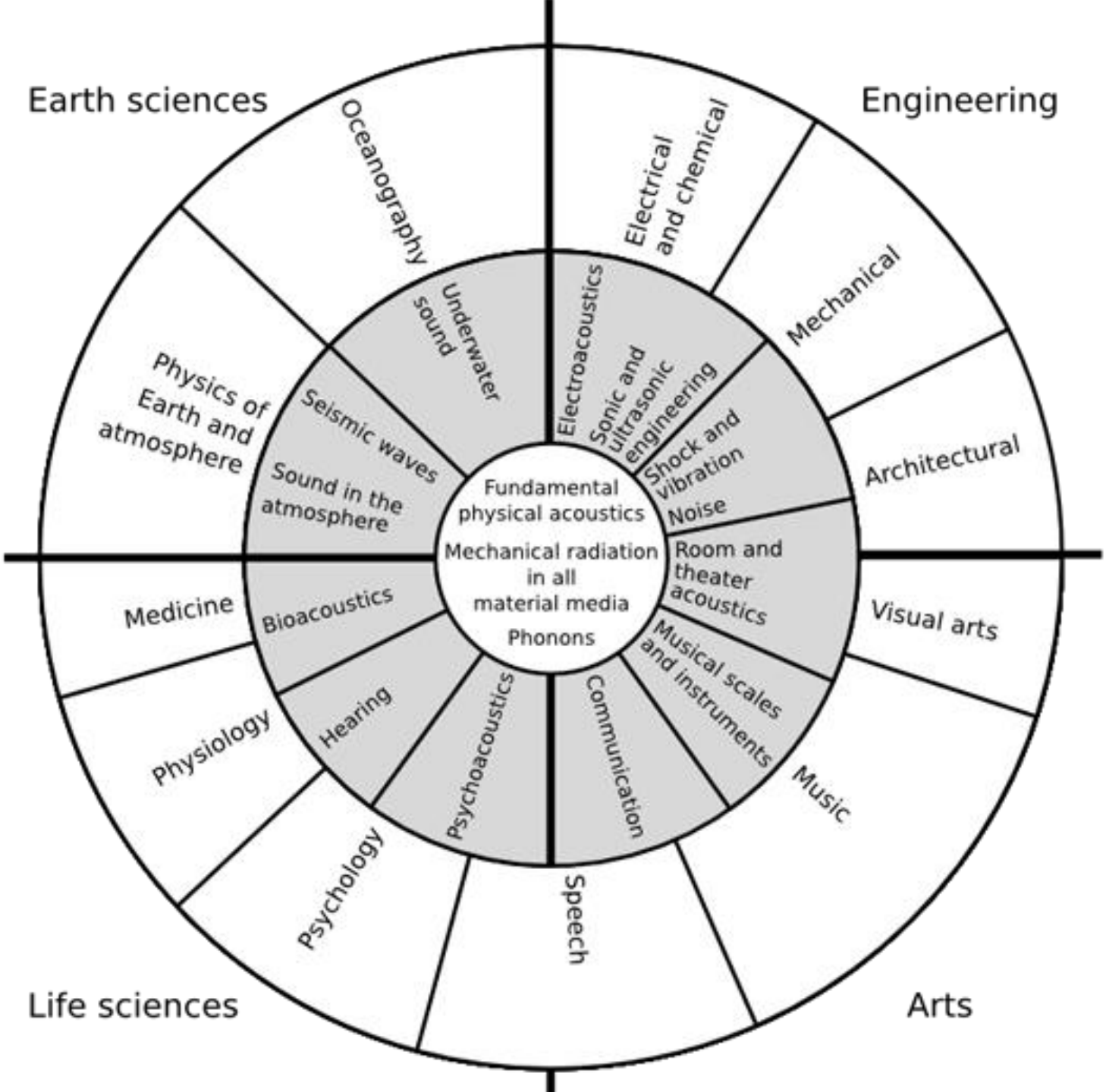
Aero acoustics
Architectural acoustics
Bioacoustics
Biomedical acoustics
Environment noise
Psychoacoustics
Physiological acoustics
Physical acoustics
Speech communication
Structural acoustics
Transduction
Musical acoustics
Underwater acoustics
Nonlinear acoustics

What is Architectural Acoustics?

Architectural Acoustics or the acoustics of interiors, the branch of acoustics concerned with

- the diffusion of sound waves in an interior,
- their reflection and absorption by surfaces, and
- the influence of reflected waves upon the audibility of speech and music.

The scope of acoustics


Earth sciences
Engineering
Life sciences
Arts
Oceanography
Electrical and chemical
Mechanical
Architectural
Visual arts
Music
Speech
Psychology
Physiology
Medicine
Physics of Earth and atmosphere
Underwater sound
Seismic waves
Sound in the atmosphere
Electroacoustics
Sonic and ultrasonic engineering
Shock and vibration
Noise
Room and theater acoustics
Musical scales and instruments
Communication
Psychoacoustics
Hearing
Bioacoustics
Fundamental physical acoustics
Mechanical radiation in all material media
Phonons

The aim of Architectural Acoustics

The *aim of architectural acoustics* is;

- To create the designs for halls (such as theater, concert, and lecture halls) and radio studios with good sound conditions
- To reduce the background noise in a recording studio
- To improve the design of a public address system to make speech more intelligible in railway stations
- To put acoustic treatments on walls to make music in a concert hall sound better
- Etc……

There are three major branches of architectural acoustics.

- **Room acoustics** involves the design of the interior of buildings to project properly diffused sound at appropriate levels and with appropriate esthetic qualities for music and adequate intelligibility for speech.

- **Noise control or noise management** involves the reduction and control of noise between a potentially disturbing sound source and a listener.

- **Sound reinforcement and enhancement systems** use electronic equipment to improve the quality of sounds heard in rooms.

Brief history of acoustics...

”*Acoustics is a science of the last thirty years*.”

Physicist Dayton Miller 1931

History...

•6th century BC

Pythagoras investigates the relation between the *length and pitch of strings*

•325 BC

Aristotle writes about the *production and reception of sound and echoes*

•27 AD

Marcus Vitruvius Pollio: *De Architectura,* first instructions on the *acoustic design of theaters*

•800s →

Islamic culture produces new knowledge on *sound-related phenomena* (e.g. Hearing and speech production)

•1500s

The effects of Renaissance cathedrals on *music*

History...

•Mid 1600s

Sound reflection and echoes are explained as analog to the reflection of light, R. Boyle ja R. Hooke deduce that sound needs a medium in order to propagate, G. Galilei investigates the vibration of strings.

•1670`s

First *purpose-built concert hall* is finished in London

•1700s

Commercialisation of music and theatre industry creates new social and acoustical framework

•1816

P. S. Laplace discovers the equation for *calculating the speed of sound* (Newton attempted this before but did not get the right result)

Beginning of 1800s

Practical research on the *behaviour of sound in enclosed spaces* (background: growing need for auditoria and development of orchestral music). C. Bullfinch, R. Millsand J. S. Russell develop methods for *improving speech intelligibility* in rooms.

•1850

Joseph Henry discovers the *Precedence effect* and evaluates that the shape of the room does not explain alone the way it sound, but materials have to be considered also

•1860s

Hermann von Helmholtz investigates *speech production, sense of hearing and sound disturbance*

•1876

A. G. Bell invents the *microphone* (however, condensator microphone is not invented until 1916)

•1877

Lord Rayleigh: *The Theory of Sound*, the mathematical principles of sound and vibration

End of 1800s

Wallace Clement Sabine hired to improve the acoustics of the Fogg Art Museum in Harvard

→Sabine invents a method for measuring the *reverberation time* of a room using an organ pipe and stop watch
→Sabine equation for calculating the reverberation time

•1895

W. C. Sabine as acoustical designer of the Boston Symphony Hall

•1920

First patented *acoustical tile*

•1927

First *anechoic chamber* built (F. Watson)

•1930s

First *sound level meter* (P. Sabine)

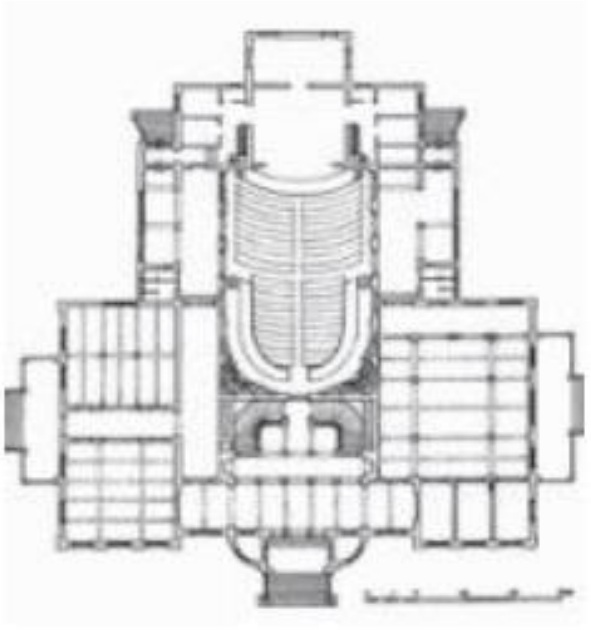
•1930s

Suggestions for sound insulation regulations in several countries, measurement of and methods to decrease traffic noise in large cities

→acoustics becomes a tool for humans to control the environment

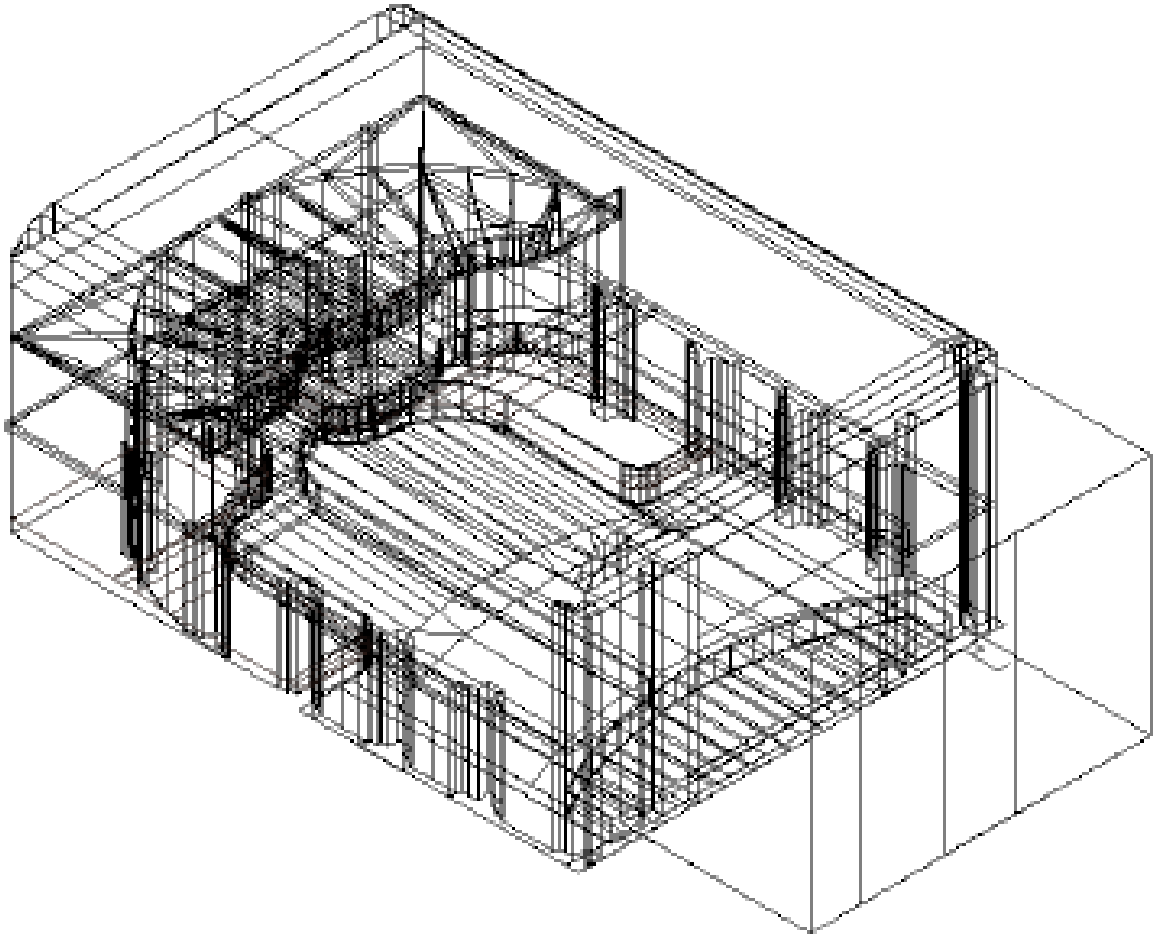
In Turkey

- El Hamra Sineması (by Tahsin Sermet Bey, İzmir, 1922-1926),
- Yıldız Sarayı 2. Abdulhamit Salonu (İstanbul), Edirne Türk Ocağı Binası (Edirne Devlet Türk Müziği Topluluğu Salonu, by Dr. Rıfat Osman Bey),
- Süreyya Paşa Opera Temsil Salonu (by Auguste and Gustave Perret, İstanbul, 1927),
- Türk Ocağı Binası/Resim Heykel Müzesi (by A. Hikmet Koyunoğlu, 1927-1930)



Resim Heykel Müzesi Multipurpose hall (beykoz-turkocagi.org.tr, 2011)

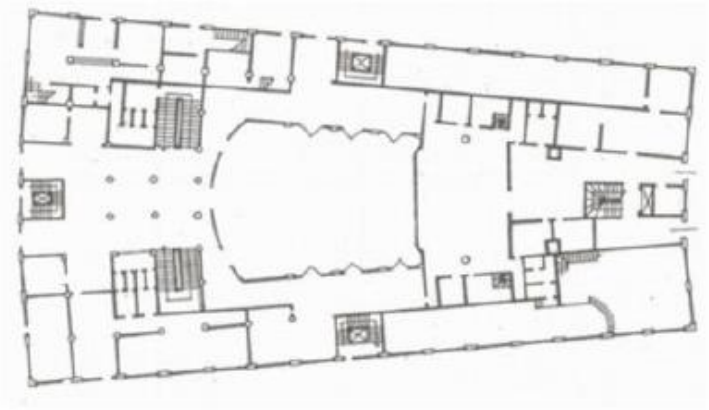
Resim Heykel Müzesi plan (Aslanoğlu, 2001)

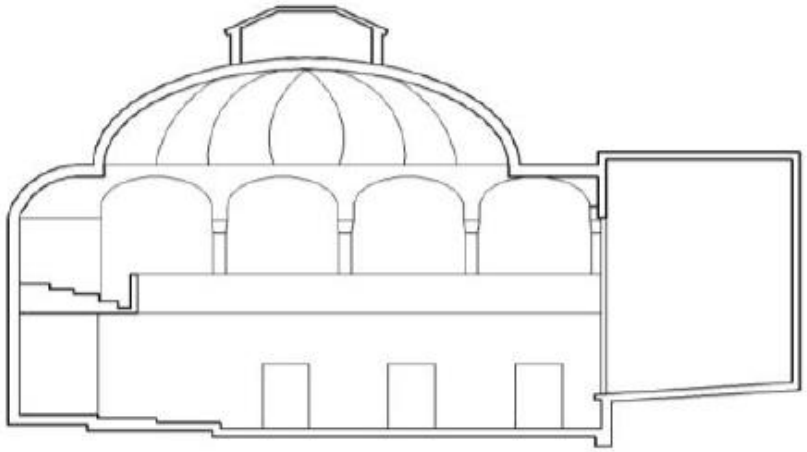


Resim Heykel Müzesi Multipurpose Hall - Axonometric view

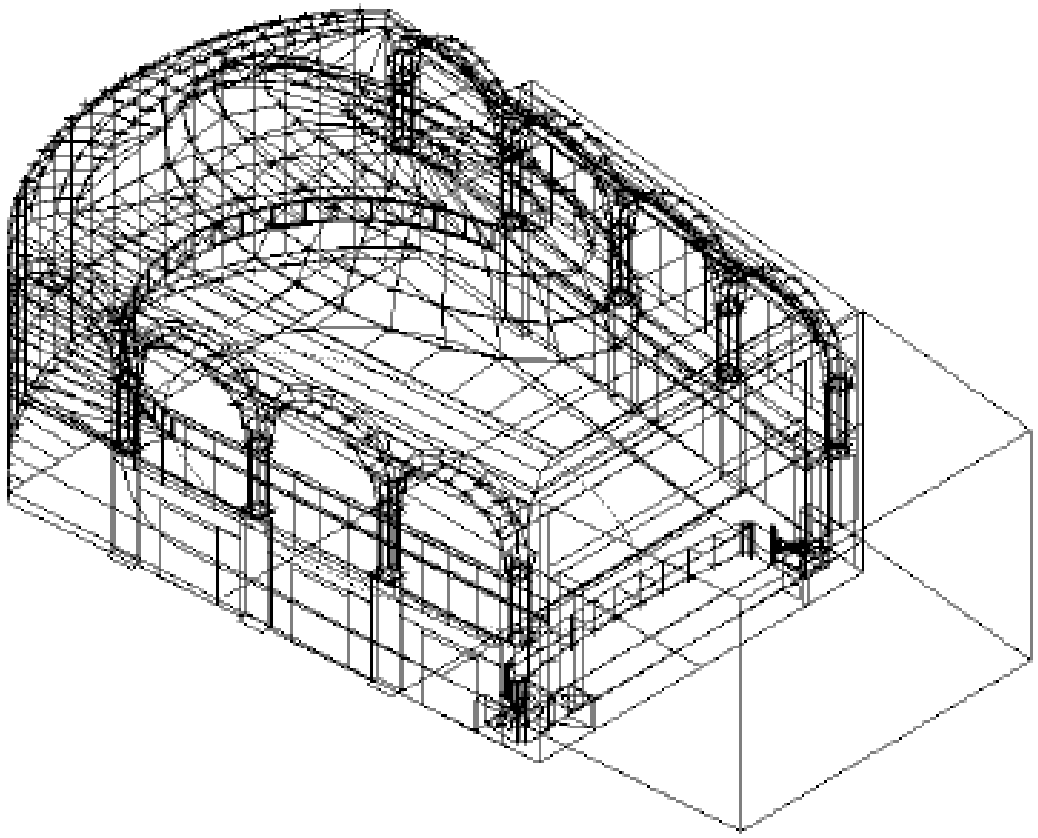
In Turkey

- II.Evkaf Apartmanı/Küçük Tiyatro (by Mimar Kemalettin, 1929





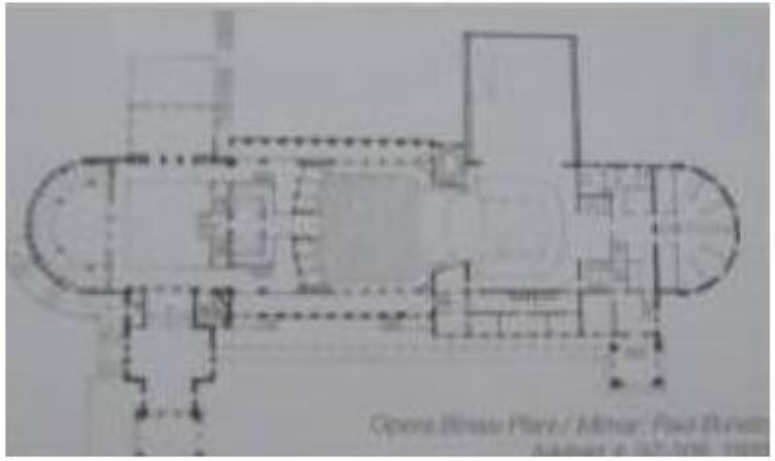
Küçük Tiyatro Hall interior view (www.devtiyatro.gov.tr, 2010)
The ground level plan of the building (Aslanoğlu, op.cit.)
The section of the building

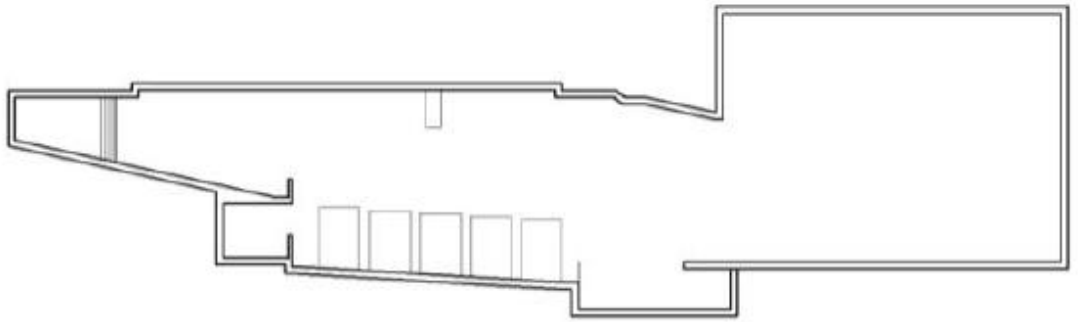


Küçük Tiyatro Hall - Axonometric view

In Turkey

- Tayyare sineması (by Arif Hikmet Koyunoğlu, Bursa, 1930-1932)
- Sergi Evi/Opera/Büyük Tiyatro (1933, the hall was designed by Paul Bonatz in 1946)

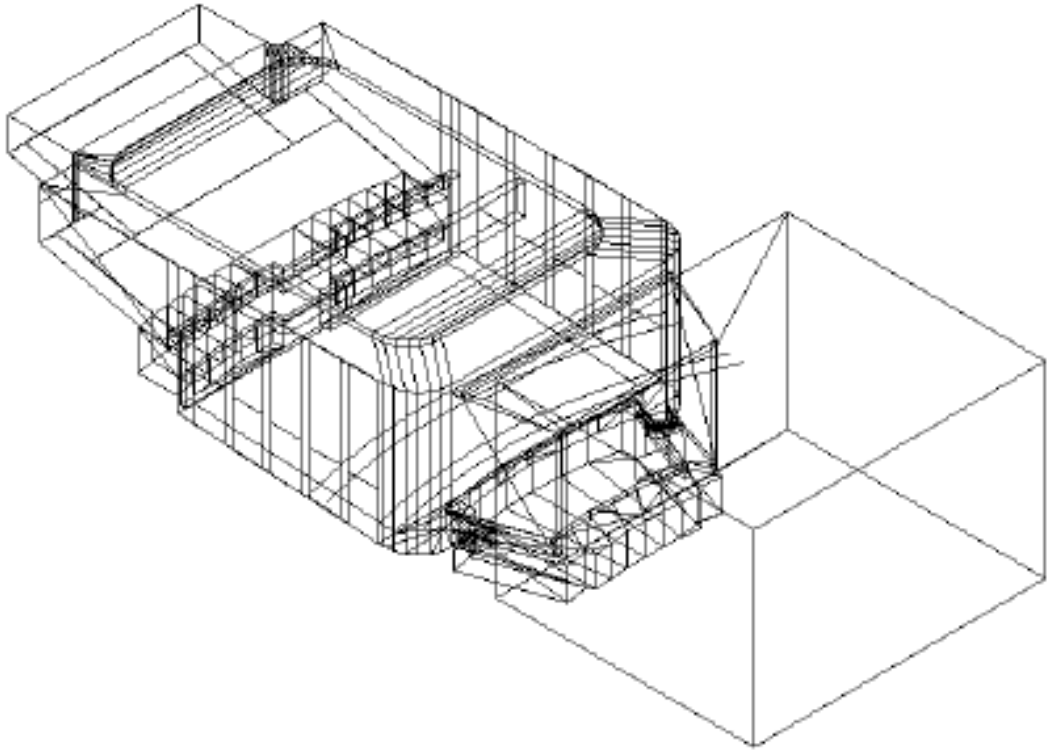




Opera Hall interior view

The plan of the ground floor of the building (Aslanoğlu, op.cit)

The section of the hall



Opera/ Büyük Tiyatro Hall - Axonometric view

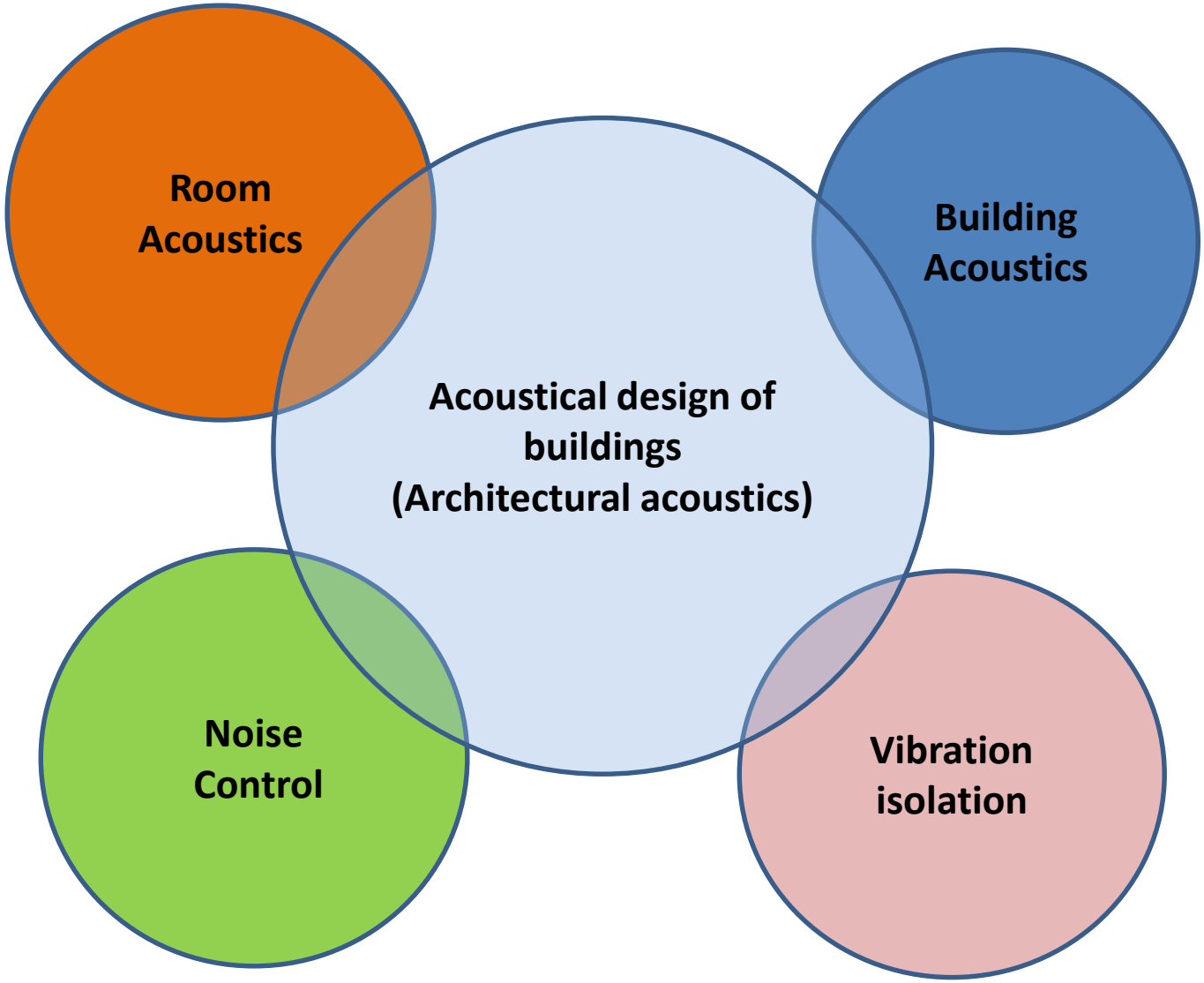
Acoustics as a field of science and technology

•Old field of science but significant effects not until the 20th century

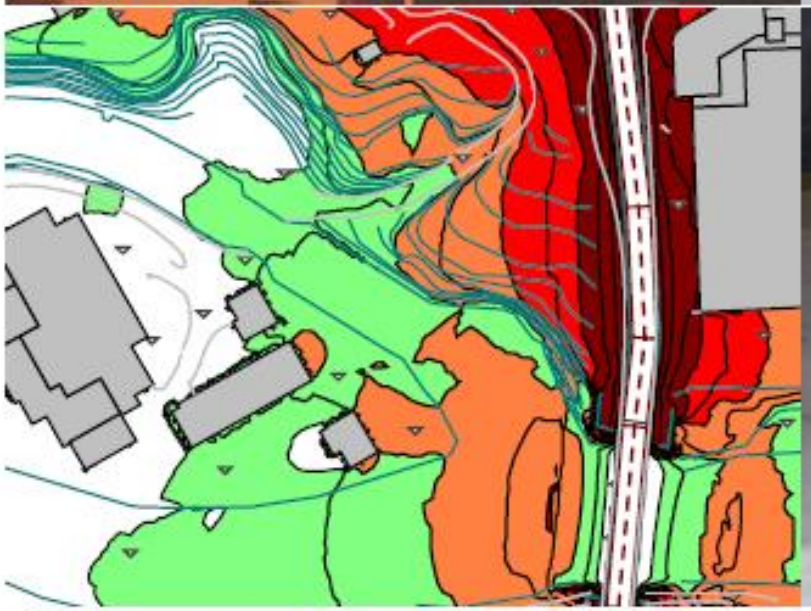
•Acoustics has enabled, e.g.
–Telephone, radio, recording and reproduction of sound, talking movies
–Hearing protection in industrial labour
–Privacy in residential buildings
–The building of spaces which work according to desired function

•Sound plays an important role in how people experience and perceive the surrounding environment
–Hearing
–Speech, communication
–Music
–Warning signals
–Sound in nature

The ”four-field” of acoustical design



The ”four-field” of acoustical design

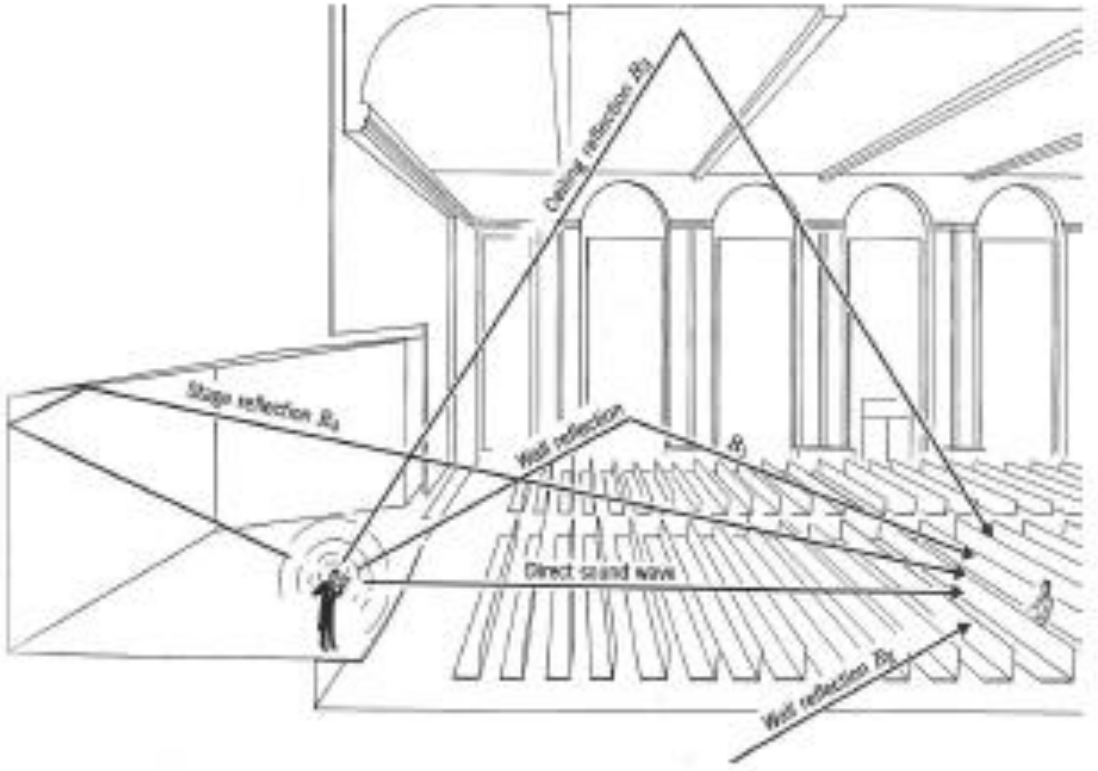


Room acoustics

- ”*Good room acoustics means that speech and music is perceived as beautiful, natural and clear in every point of the room.” EngineerU. Varjo 1938*

- The reflection, attennuation and propagation of sound in a space

- Goal: sound (speech, orchestra etc.) sounds as is required by the *use of space*

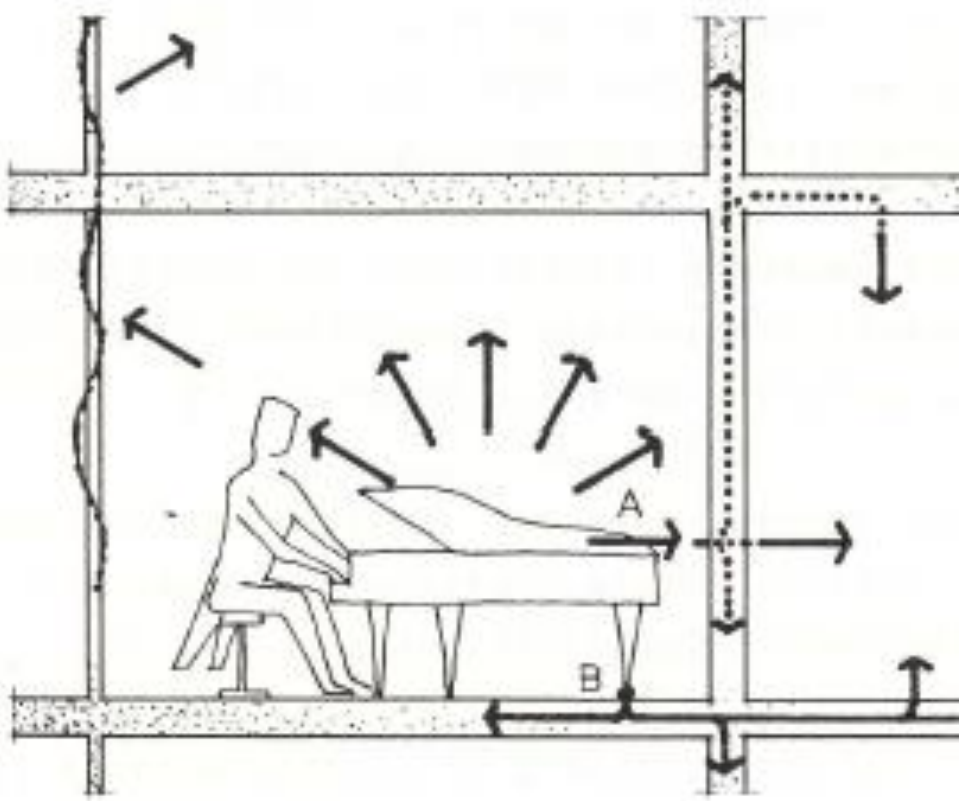


Building acoustics

- Transition of sound between space svia structures
  - –Not only through the separating structure, but also as *flanking transmission* *and through holes etc.*

- 3 parts depending on the nature of the sound source:

  - –*Airborne sound insulation*
  - –*Impact sound insulation*
  - –*Structure-borne sound insulation*



Building acoustics

- *Sound insulation*

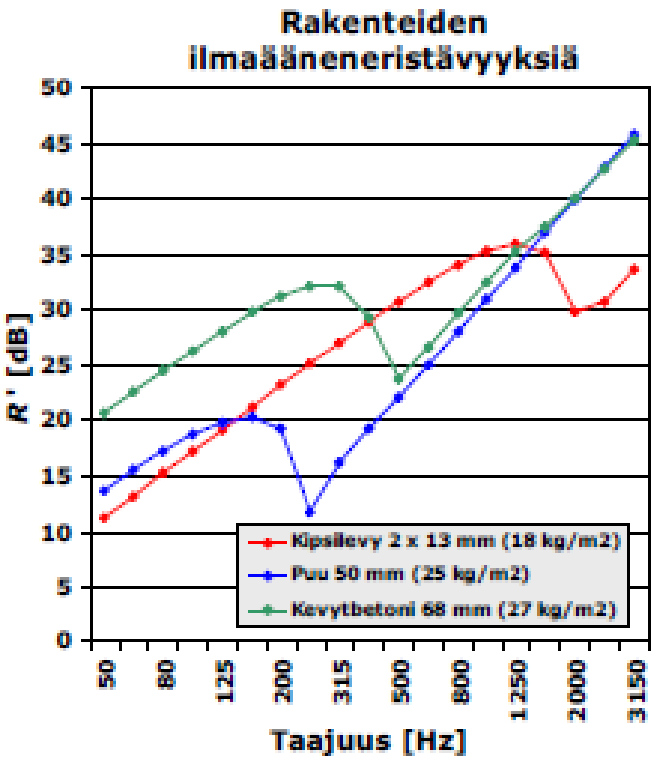
–Between spaces (airborne and impact)

–From inside to outside and vice versa

–Equipment noise

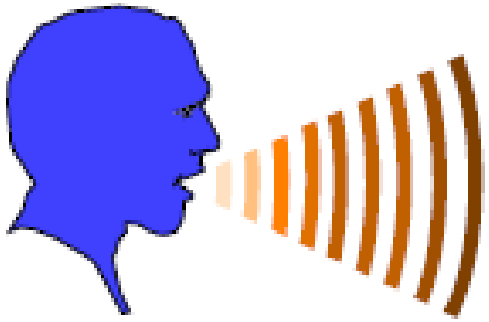
–Vibration

- Choosing the *construction type* is also acoustic design



Building acoustics

Airborne sound *is sound produced in and propagated in air, whereas structure-borne sound propagates in structures*



- Speech is airborne sound

- Sounds caused by walking or dropping objects on the floor are **impact sound**

- Piano produces airborne sound and structure-borne sound through its feet which are in contact with the floor structure

- All technical equipment produce both airborne and structure-borne sound

Noise Control

- Outdoor noise sources

road, railway and airplane traffic

- Indoor noise sources

machinery and service equipment

- Goal

to diminish the production and propagation of noise

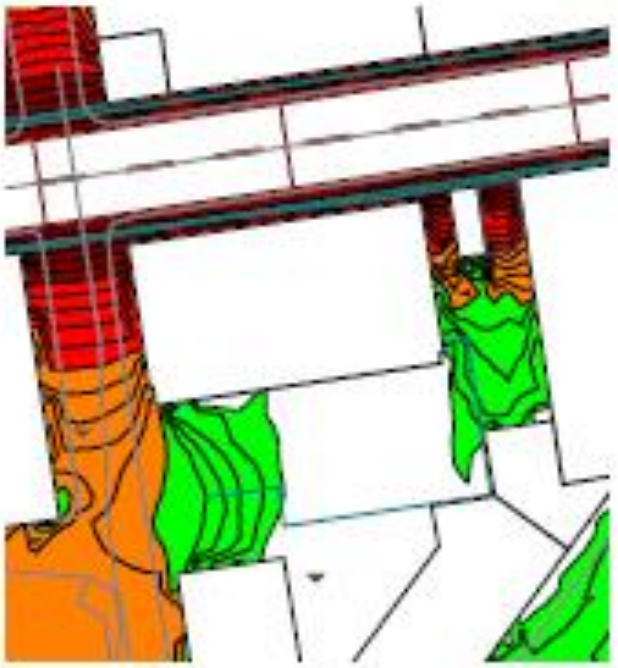
Noise Control

- HVAC equipment
  - –outdoors
  - –indoors

- Traffic noise
  - –Road traffic
  - –Railway traffic
  - –Airplane traffic
- Machinery, industry

- Measurement of noise emission

- Noise modelling

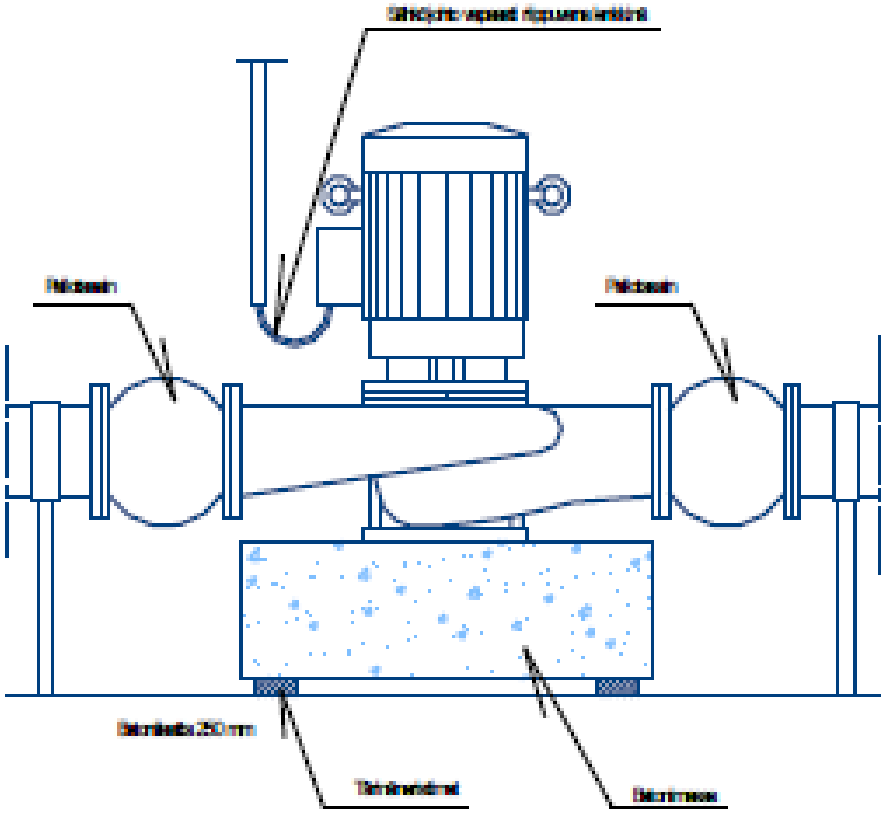


Vibration isolation

- All machinery in contact with the building frame *vibrate and produce sound*

- Goal

 to diminish the propagation of the vibration energy *by isolating* the machine from the building frame using elastic building elements



Goals of acoustical design

➢*Suitability to intended use*

–Suitability to speech/ music

–Appropriate sound insulation between spaces

➢*Healthiness*

–Hearing loss

–Acoustic ergonomy

➢*Comfort*

–Living spaces in noisy areas

–Connection between acoustics and aesthetics

➢*(”wow-factor”)*

–Concert hall setc.

Kuokkala church 2010
Lassila Hirvilammi Arkkitehdit,
Helimäki Acoustics

Significance of acoustical design

- The starting points of acoustic design:

1. Healthiness
2. Comfort
3. Use of space

- Achieving good acoustical conditions in a building requires *that all the points are taken into consideration!*

- The need of acoustical design is not limited to demanding spaces such as concert halls, but acoustical design is needed in every day buildings as well (when, e.g., choosing the construction type of a sound-insulating structure in a school or residential building)

Significance of acoustical design

Sound constitutes a significant part of the human sensory environment

- *Noise ("unwanted sound") has significant physiological and psychological effects on humans*

–Research has been extensive from the beginning if the 20th century
–The effects of noise are not limited to *loud noise* (hearing damage risk), but also a *quiet sound* can be perceived as noise if it, for example, hinders concentration

- *Bad acoustics* also has economic consequences...

Significance of acoustical design

Investing in acoustics is worth it

- A space which does not function acoustically as required by its use is a stranded investment, i.e. bad business!
- *Improving the acoustical conditions* in a finished building is always expensive
  - –Meetings
  - –Measurements
  - –Work of experts
  - –Work spent by the user to solve the problem
  - –Larger design costs
  - –Larger building costs

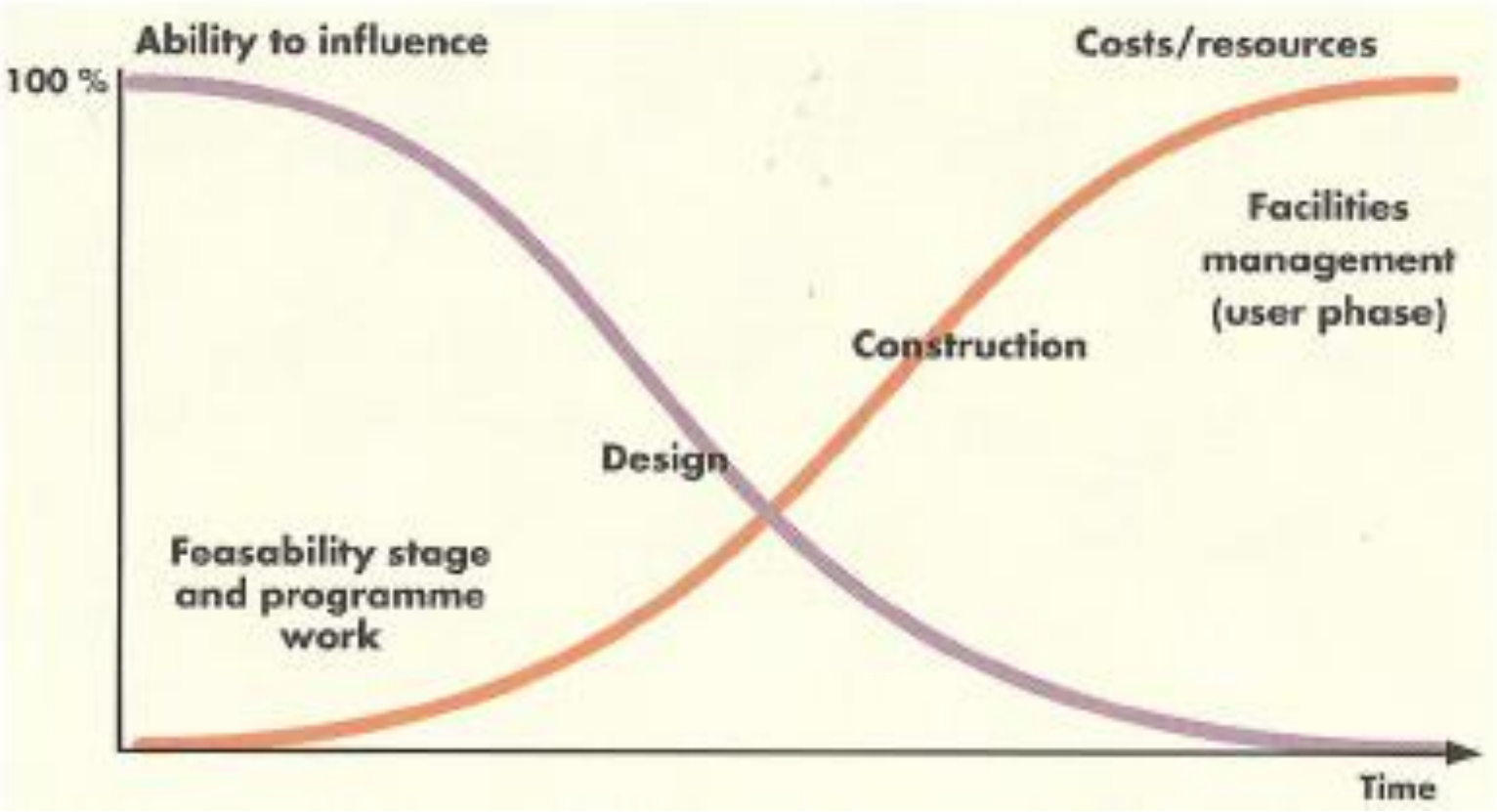
- Savings earned during the use of the building
  - –The effects of acoustics on working conditions
  - –There *is no need to do changes* to a space which works as intended!

Regulations and instructionin acoustics

The National Building Code of Finland, Section C1-1998

- The National Building Code of Finland, SectionD2-2010
- Asumisterveysohje (2003) by the Ministry of Social Affairs and Health
- Government Decision on the Noise Level Guide Values (993/1992)
- Acoustic Clasification of Spaces in Buildings, standard SFS 5907

Acoustics in the building project



Acoustics should be considered in the building project as soon as possible –the sooner, the more demanding the project is!

Project planning phase

Sound insulation

–Appropriate level of sound insulation according to use of spaces

–Space program*: positioning of noisy / quiet spaces*

- Room acoustics

–Use of space surface area, volume, shape, room acoustical materials

- Control of HVAC noise

–Determine the permitted noise levels

–Space needs required by noise control measures (silencers etc.), positioning of engine rooms and noisy machinery

- Control of traffic noise

–Noise surveys (recommendations, e.g., for positioning of buildings, estimate of the need for facade sound insulation

–Vibration surveys

Preliminary design phase

- Sound insulation

–Definition of sound insulation target values

–Construction types of separating and flanking structures, sound insulation requirements of doors, floor coverings

- Room acoustics

–Basic shape of speech and performance spaces, room acoustical requirements as technical values (e.g., reverberation time)

–Amounts and types of room acoustical materials, furnishings and decoration

- Control of HVAC noise

–Permitted HVAC noise levels according to the uses of spaces and principles of how the target values can be fulfilled, selection of sewer system

- Control of traffic noise

–More accurate noise survey (requirements for facade sound insulation, balcony glazings, noise barriers), effects of vibration surveys

–Determination of construction types: exterior wall (US), roof (YP) (sufficient sound insulation for a given use)

–Facade sound insulation survey

➢Cost for the project

Implementation planning phase

- Control of traffic noise

–FSS (facade sound insulation survey) ready in time bofore ordering windows and doors (unless already required in the building permit phase), supplementations and/or correctiong to FSS if needed

–Final selection of noise barries Meluesteiden lopullinen valinta (in collaboration with the architect)

- Sound insulation

–Presentation of the details of structural joints for the structural designer, drawing of details if needed

–Supervision of structutal design so as to ensure that the sound insulation of joints and building elements corresponds to set requirements

- Room acoustics

–Positioning of room acoustical materials in different spaces to the architect, approval of furnishings etc. selected by the interior designer

–Structural designer checks the possible effects of room acoustical materials assigned to the surfaces US, YP etc. structures

Implementation planning phase

- Control of HVAC noise

–HVAC designer presents the acoustical designer pressure drop calculations, equipment lists, HVAC drawings and noise data on all equipment, fans etc.

–Sound insulation of machine room structures, noise level caused by HVAC equipment to inside spaces and outside, sound insulation through ducts -> determination of duct silencers

–Selection of vibration isolators for technical equipment and implementation of vibration isolation (principles)

–Instructions of pass-throughs and sealings: ducts, electrical installations, heating pipes etc., possible elastic couplings and brackets

➢ ***All information either to documents of other designers or to an acoustical specification, which is distributed to all building contractors.***

Implementation planning phase

- Training of construction workers if needed

–Why is something done?

–What is important from the acoustical viewpoint?

- Check the effects of possible changes to plans

–Construction types, details, changes occuring on the building site

–Changes due to selection of HVAC equipment (typically affect the design of silencers)

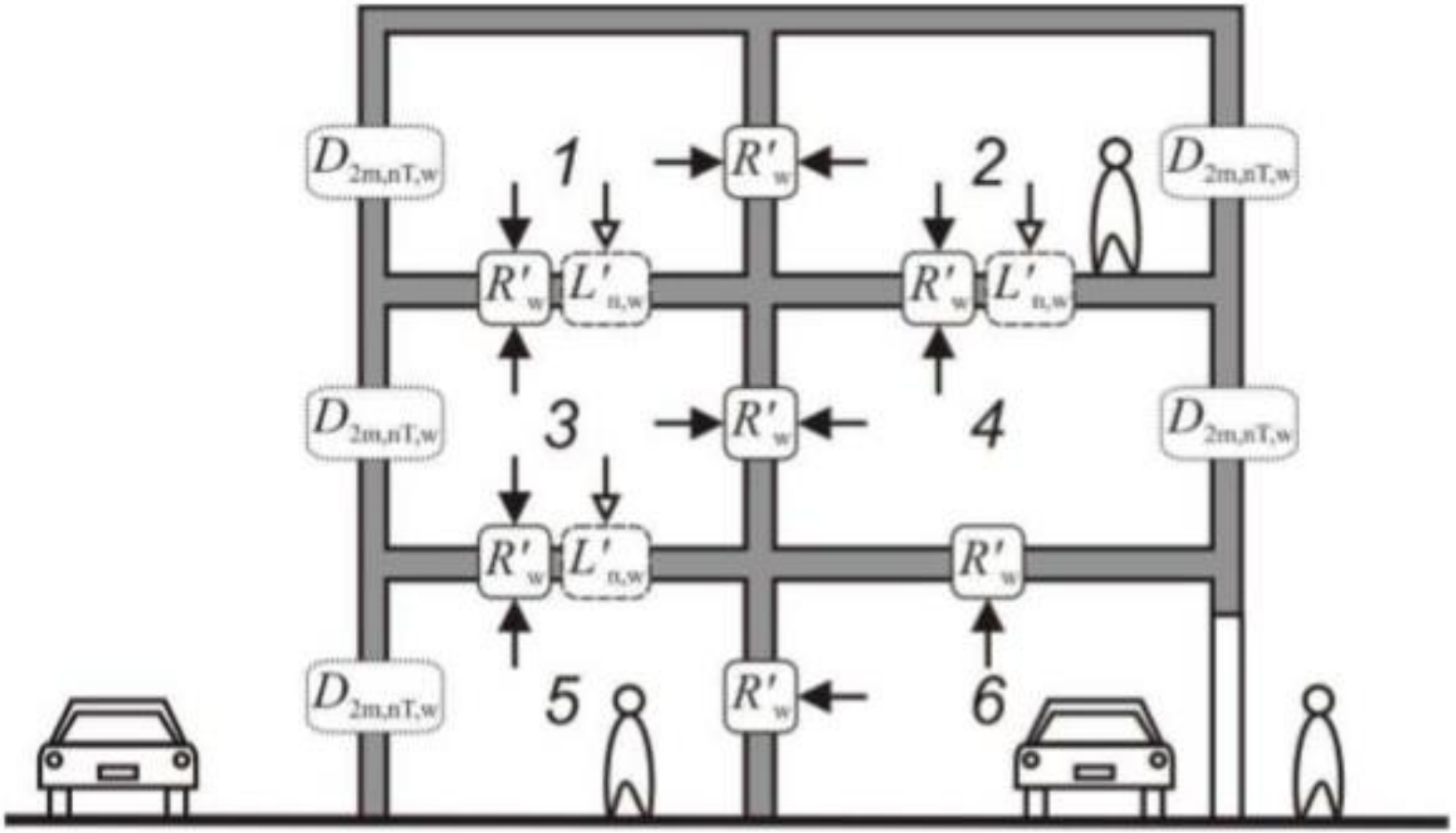
–Inspection of vibration isolators

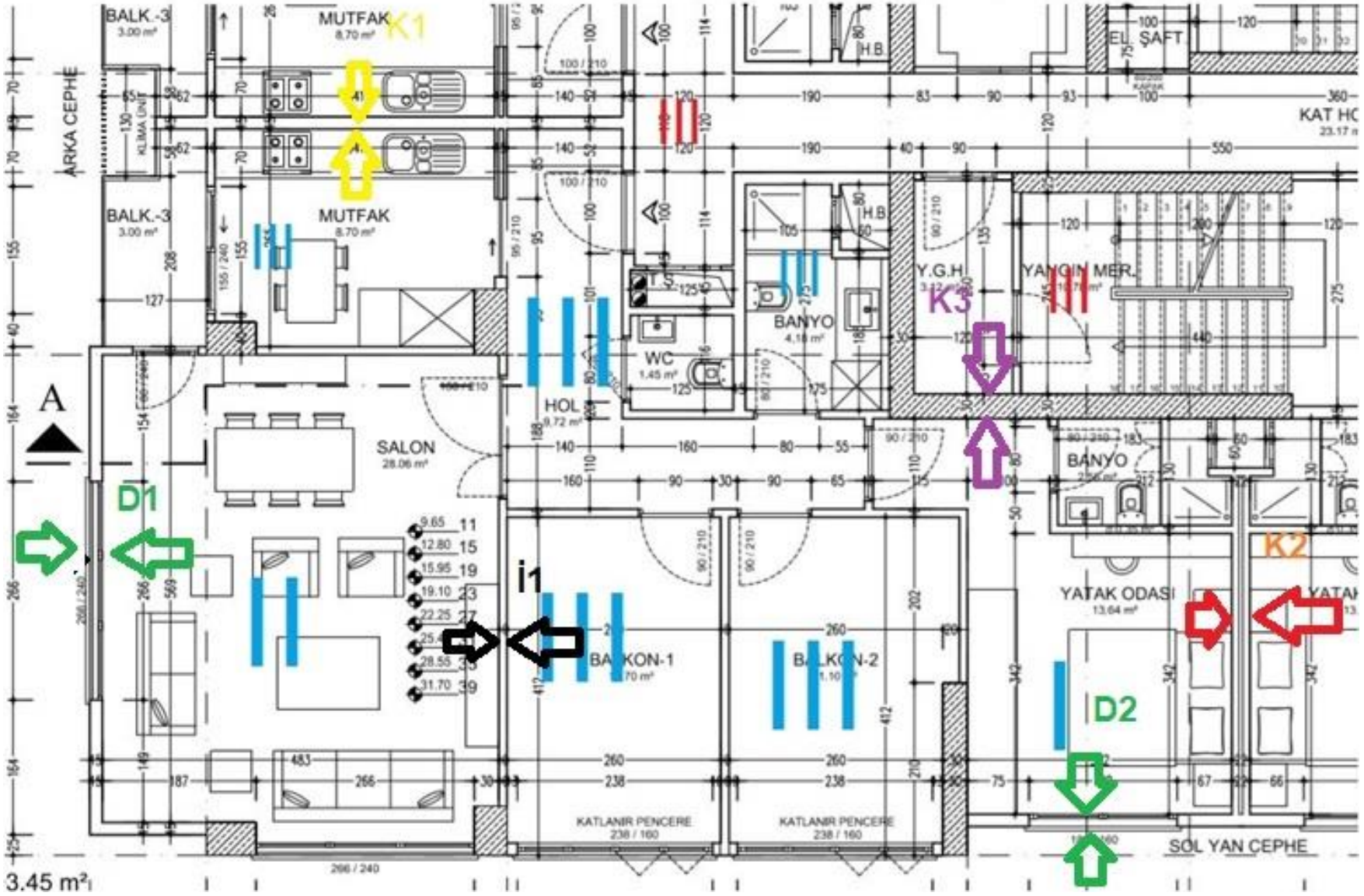
- Site supervision and inspection visits in demanding projects
- Control measurements

➢ Implementation according to plans

Application
Acoustic Report

Building Shell and Classification of Rooms

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MUTFAK
8.70 m²
K1
ARKA CEPHE
KLİMA ÜNİT.
MUTFAK
8.70 m²
BALK.-3
3.00 m²
H.B
EL. ŞAFT
KAT HO
Y.G.H
K3
YANGIN MER.
BANYO
4.16 m²
WC
1.45 m²
HOL
9.72 m²
SALON
28.06 m²
A
D1
BANYO
K2
YATAK ODASI
13.64 m²
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BALKON-1
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KATLANIR PENCERE
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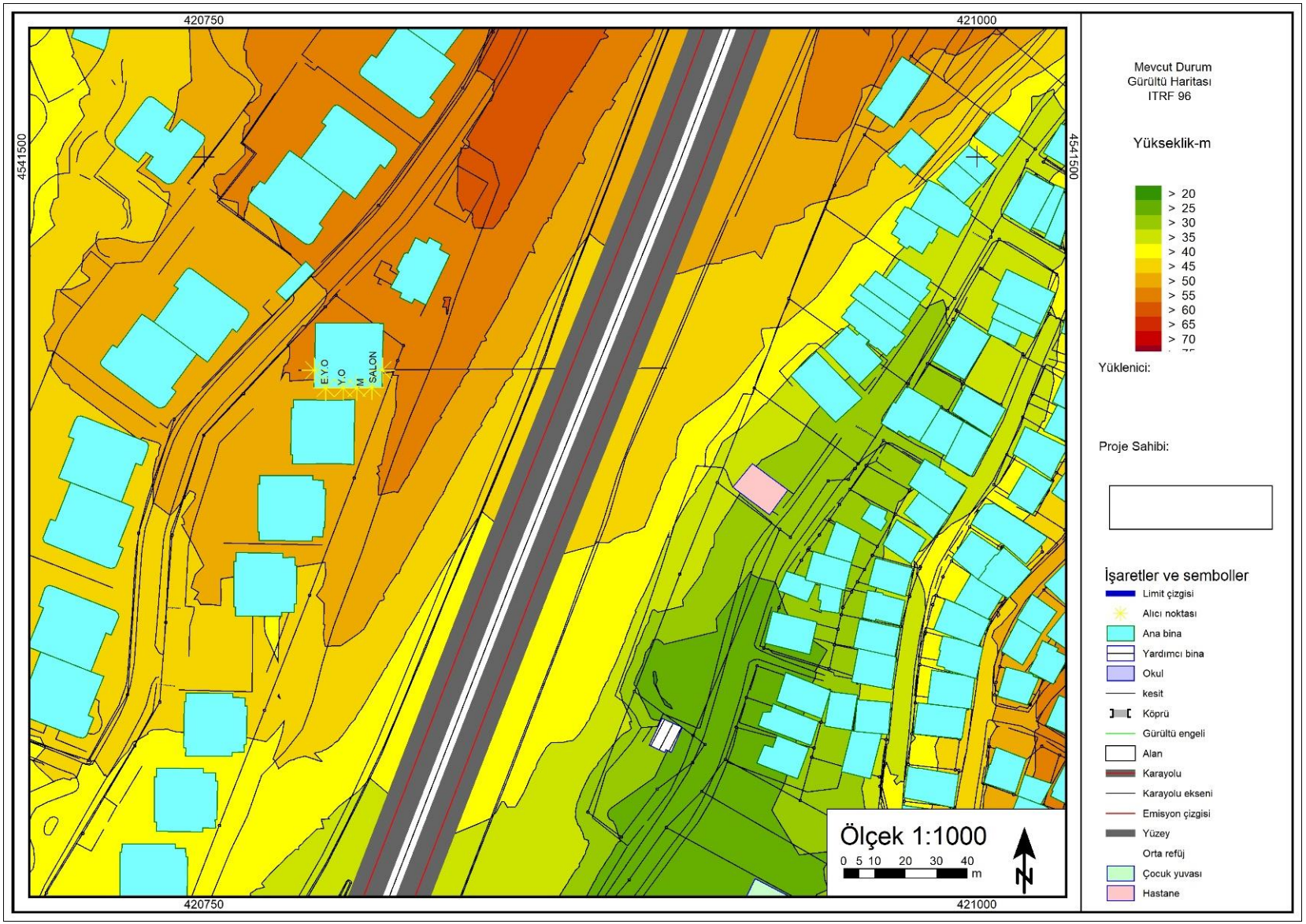
3.45 m²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Yardımcı bina
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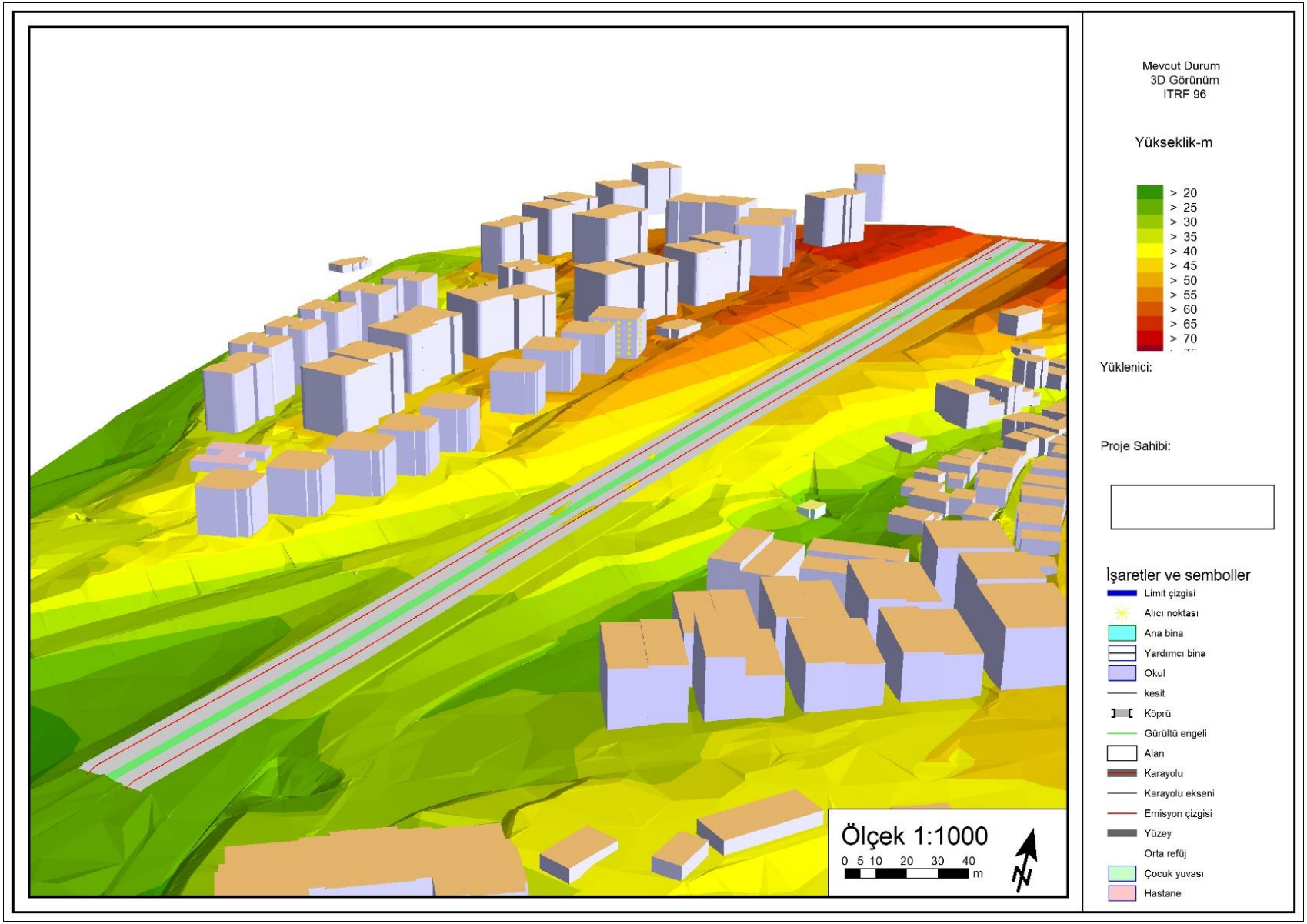
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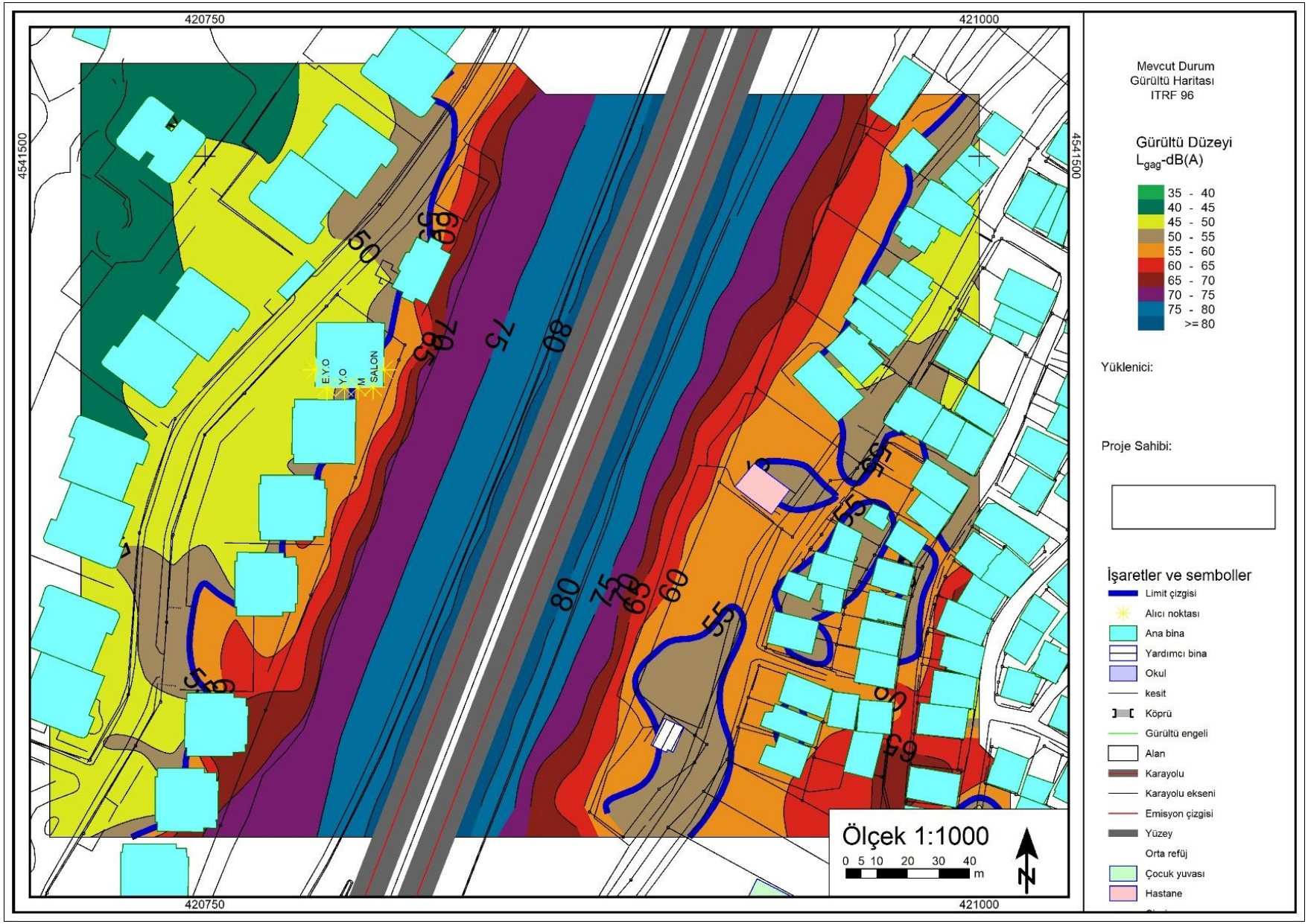
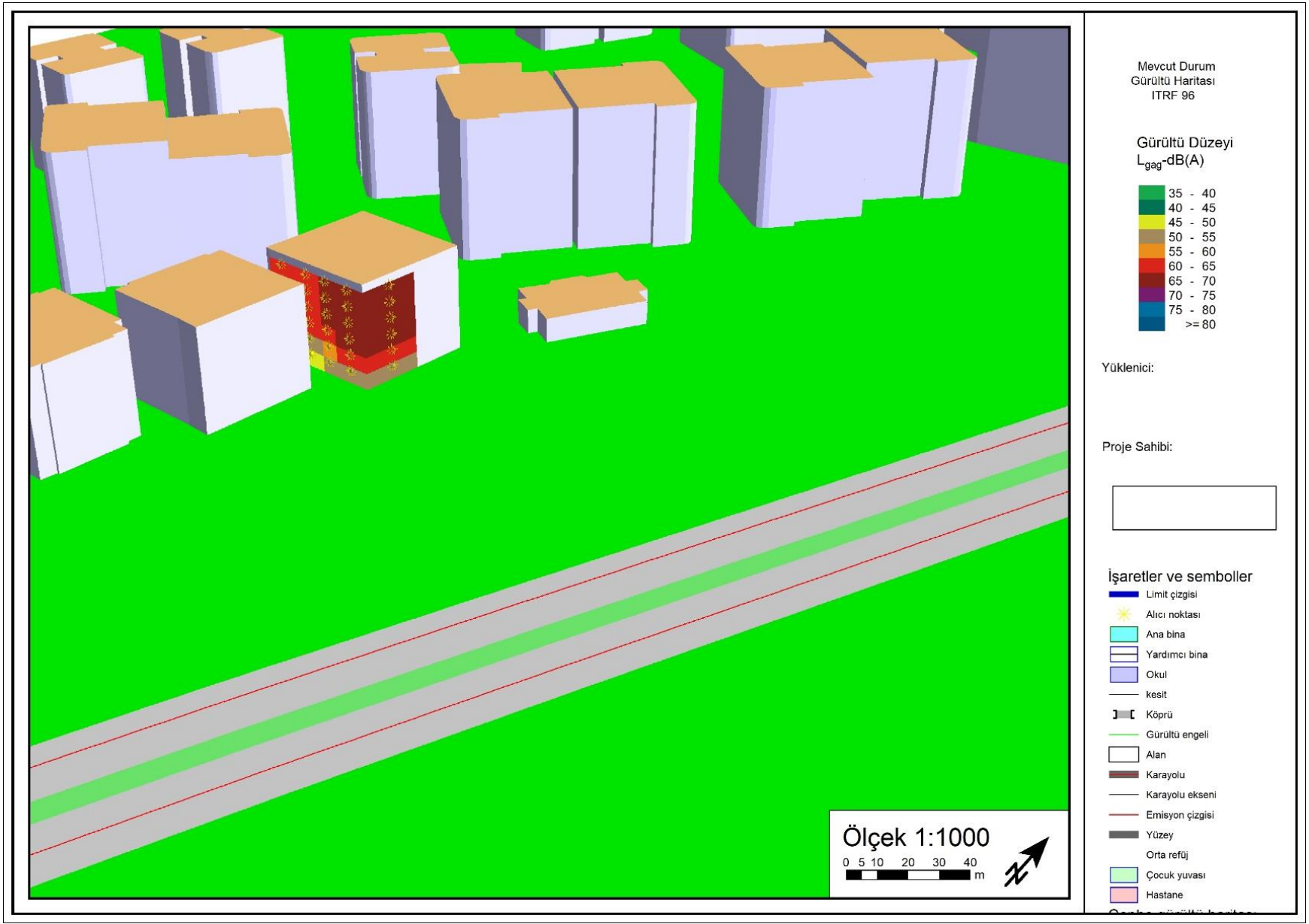
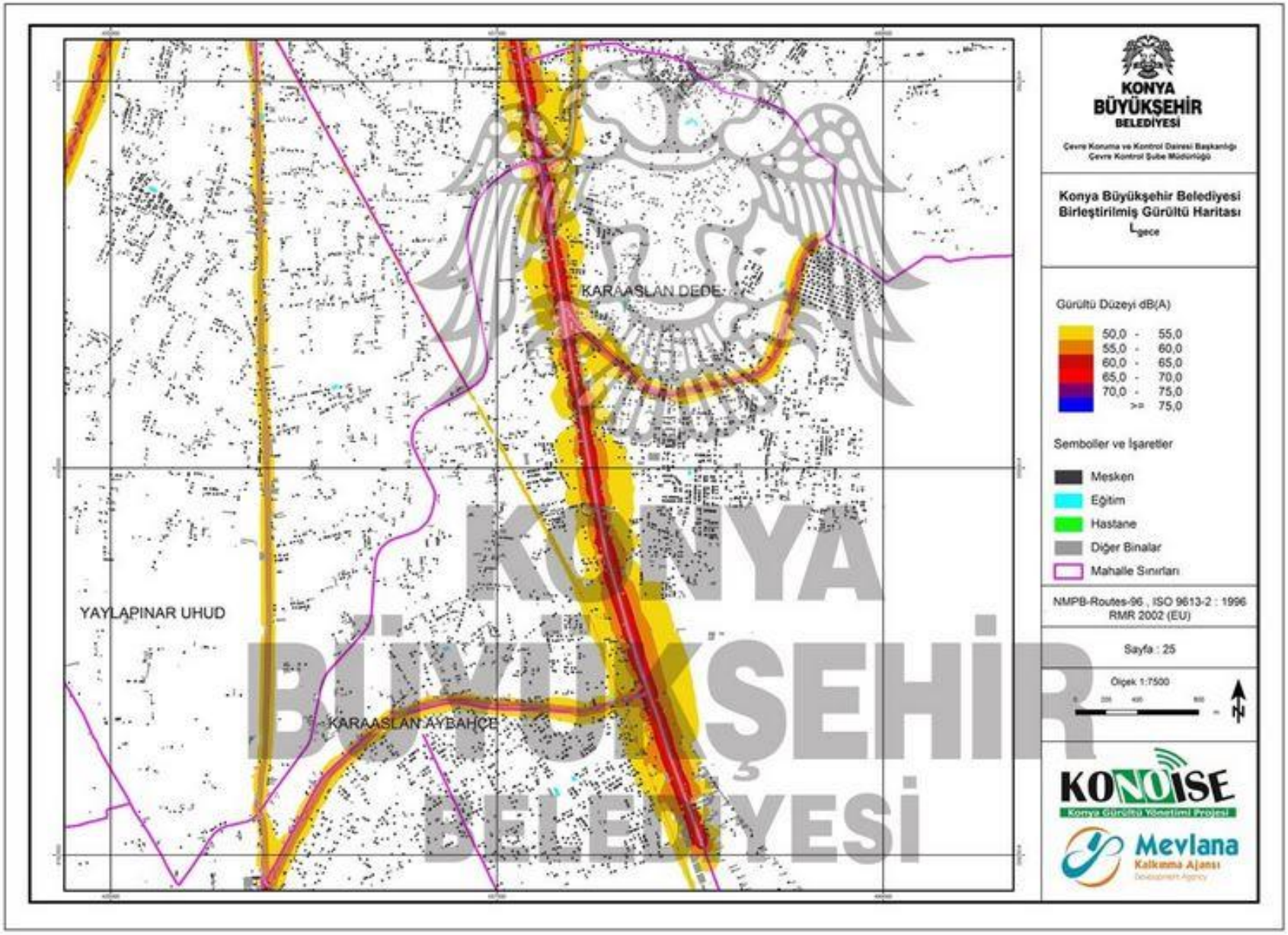
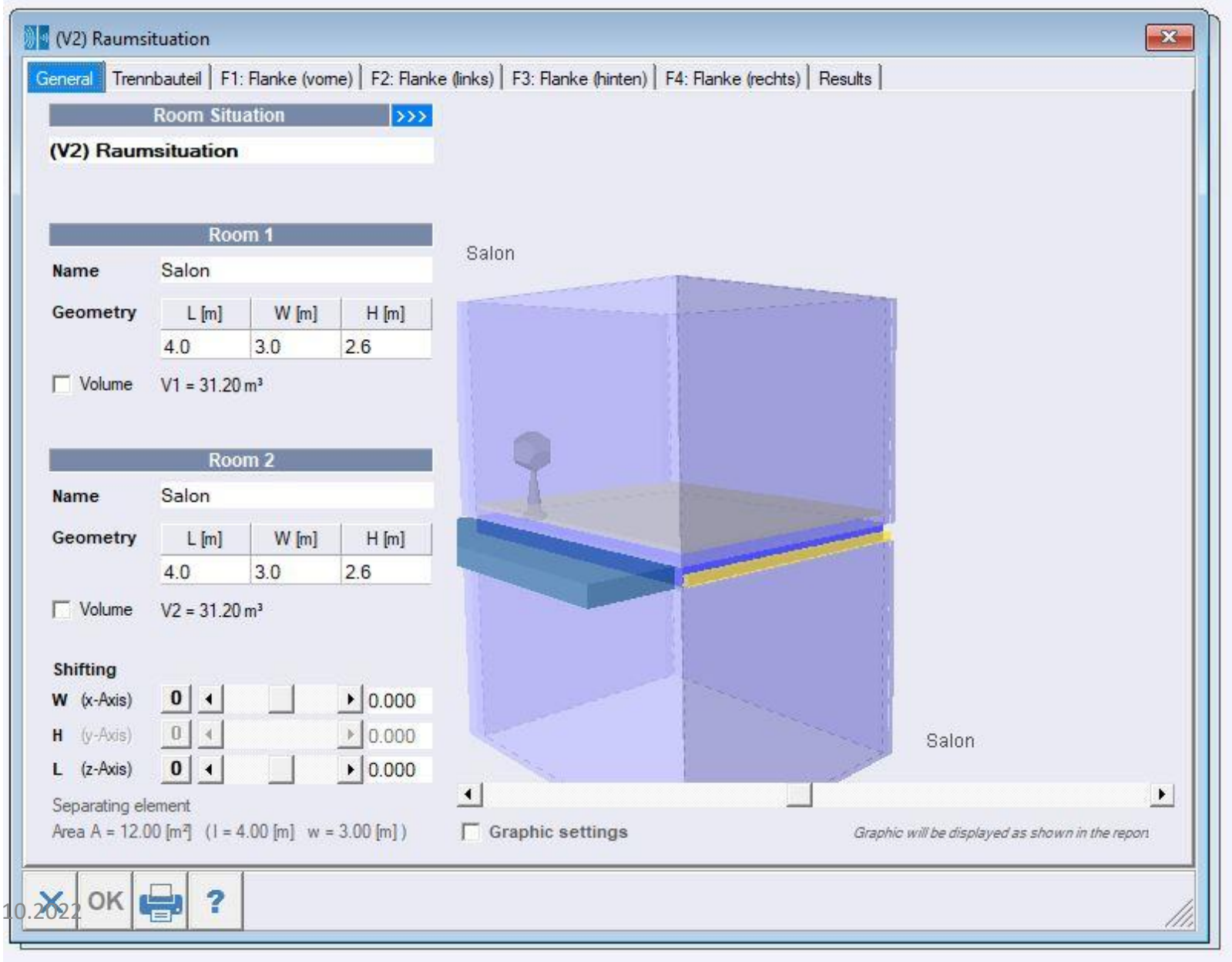
Ana bina
Yardımcı bina
Okul
kesit
Köprü
Gürültü engeli
Alan
Karayolu
Karayolu ekseni
Emisyon çizgisi
Yüzey
Orta refüj
Çocuk yuvası
Hastane
Ölçek 1:1000
0 5 10 20 30 40
m
N

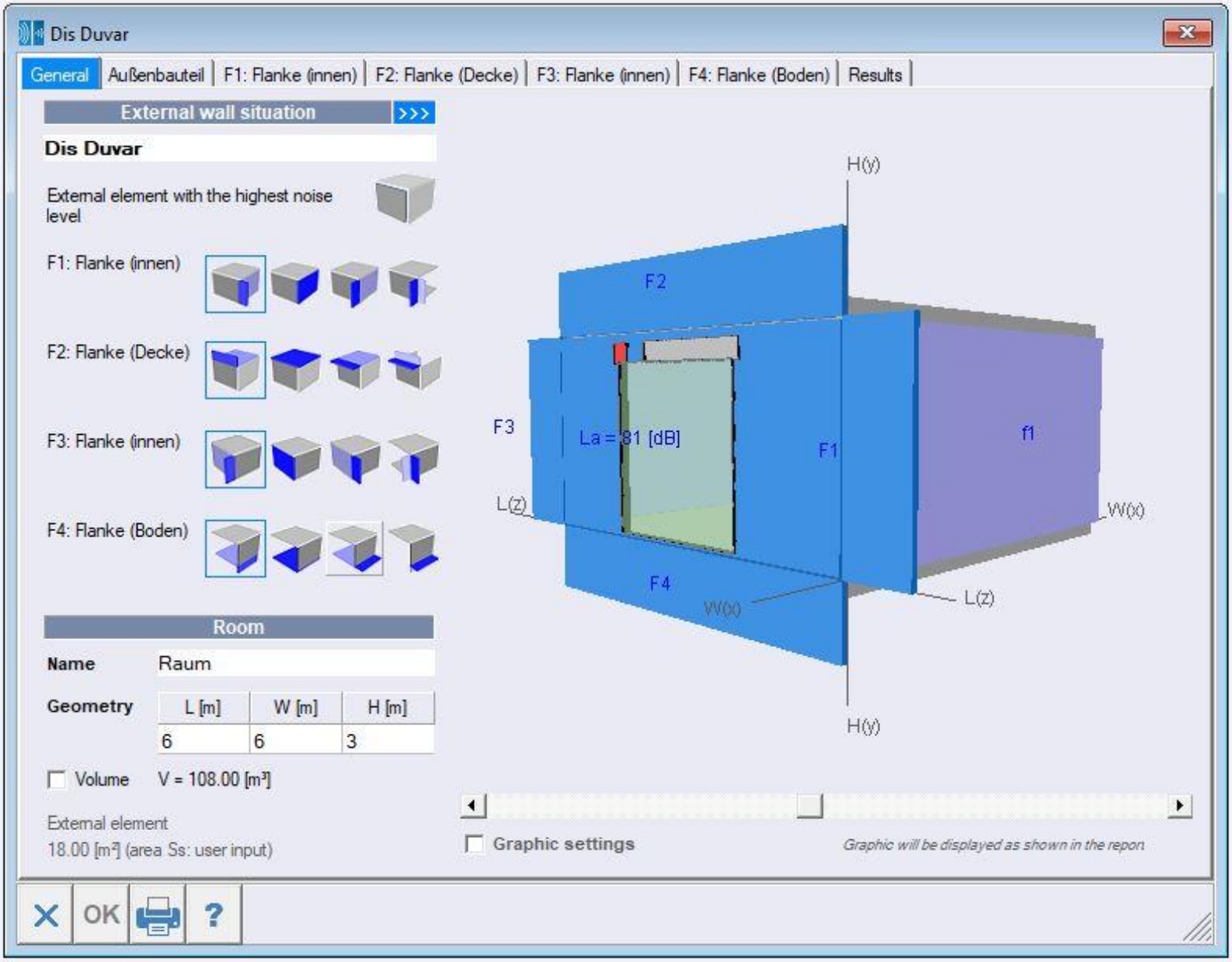

420750
421000
4541500
Mevcut Durum
Gürültü Haritası
ITRF 96
Gürültü Düzeyi
L_{gag}-dB(A)
35 - 40
40 - 45
45 - 50
50 - 55
55 - 60
60 - 65
65 - 70
70 - 75
75 - 80
>= 80
Yüklenici:
Proje Sahibi:
İşaretler ve semboller
Limit çizgisi
Alıcı noktası
Ana bina
Yardımcı bina
Okul
kesit
Köprü
Gürültü engeli
Alan
Karayolu
Karayolu ekseni
Emisyon çizgisi
Yüzey
Orta refüj
Çocuk yuvası
Hastane
Ölçek 1:1000
0 5 10 20 30 40 m
N
E.Y.O
Y.O
M
SALON


Mevcut Durum
Gürültü Haritası
ITRF 96
Gürültü Düzeyi
L_{gag}-dB(A)
35 - 40
40 - 45
45 - 50
50 - 55
55 - 60
60 - 65
65 - 70
70 - 75
75 - 80
>= 80
Yüklenici:
Proje Sahibi:
İşaretler ve semboller
Limit çizgisi
Alıcı noktası
Ana bina
Yardımcı bina
Okul
kesit
Köprü
Gürültü engeli
Alan
Karayolu
Karayolu ekseni
Emisyon çizgisi
Yüzey
Orta refüj
Çocuk yuvası
Hastane
Ölçek 1:1000
0 5 10 20 30 40
m
N

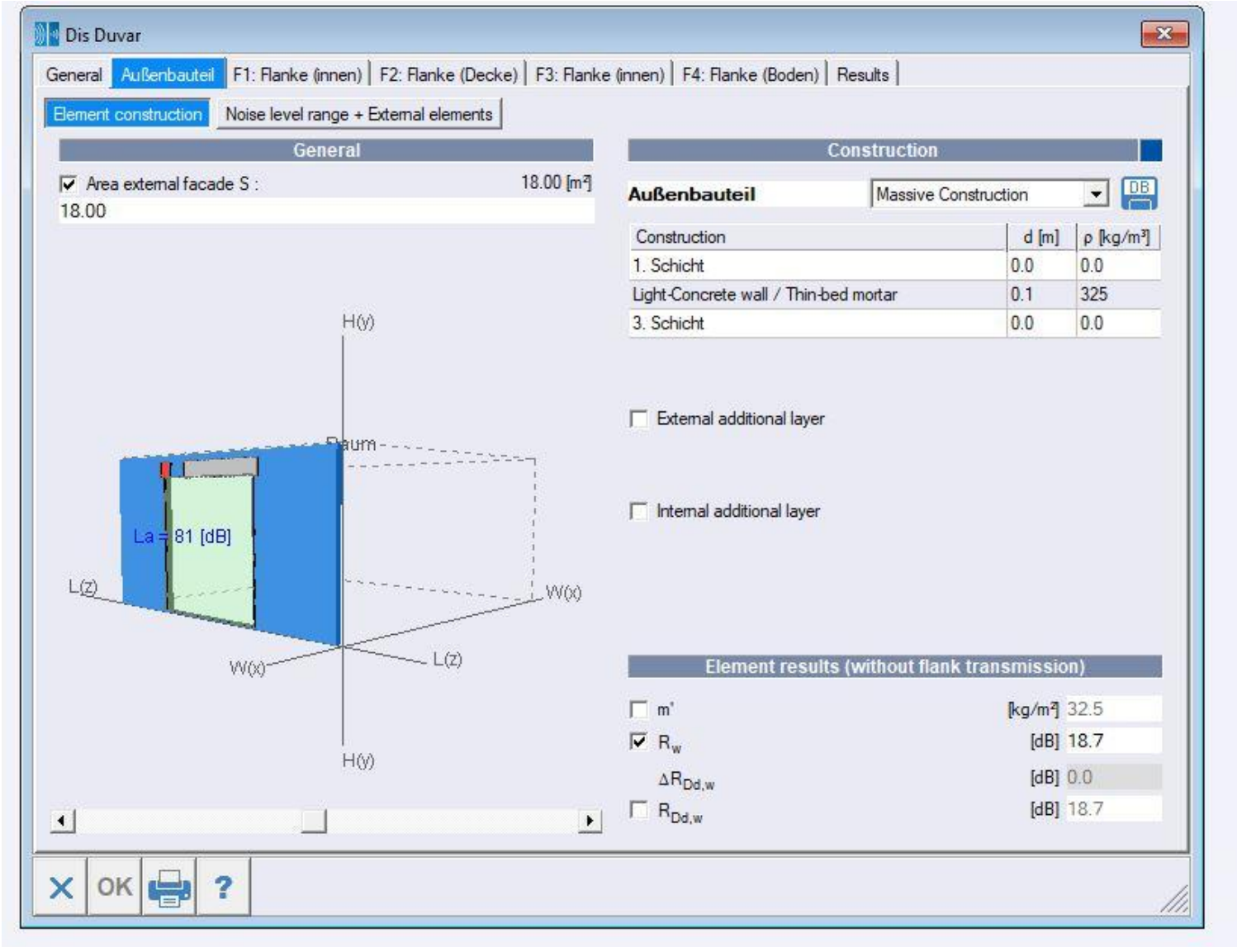

KONYA
BÜYÜKŞEHİR
BELEDİYESİ
Çevre Koruma ve Kontrol Dairesi Başkanlığı
Çevre Kontrol Şube Müdürlüğü
Konya Büyükşehir Belediyesi
Birleştirilmiş Gürültü Haritası
L_{gece}
KARAASLAN DEDE
YAYLAPINAR UHUD
KARAASLAN AYBAHÇE
Gürültü Düzeyi dB(A)
50,0 - 55,0
55,0 - 60,0
60,0 - 65,0
65,0 - 70,0
70,0 - 75,0
>= 75,0
Semboller ve İşaretler
Mesken
Eğitim
Hastane
Diğer Binalar
Mahalle Sınırları
NMPB-Routes-96 , ISO 9613-2 : 1996
RMR 2002 (EU)
Sayfa : 25
Ölçek 1:7500
KONOISE
Konya Gürültü Yönetimi Projesi
Mevlana
Kalkınma Ajansı

Reporting with KS –External Wall

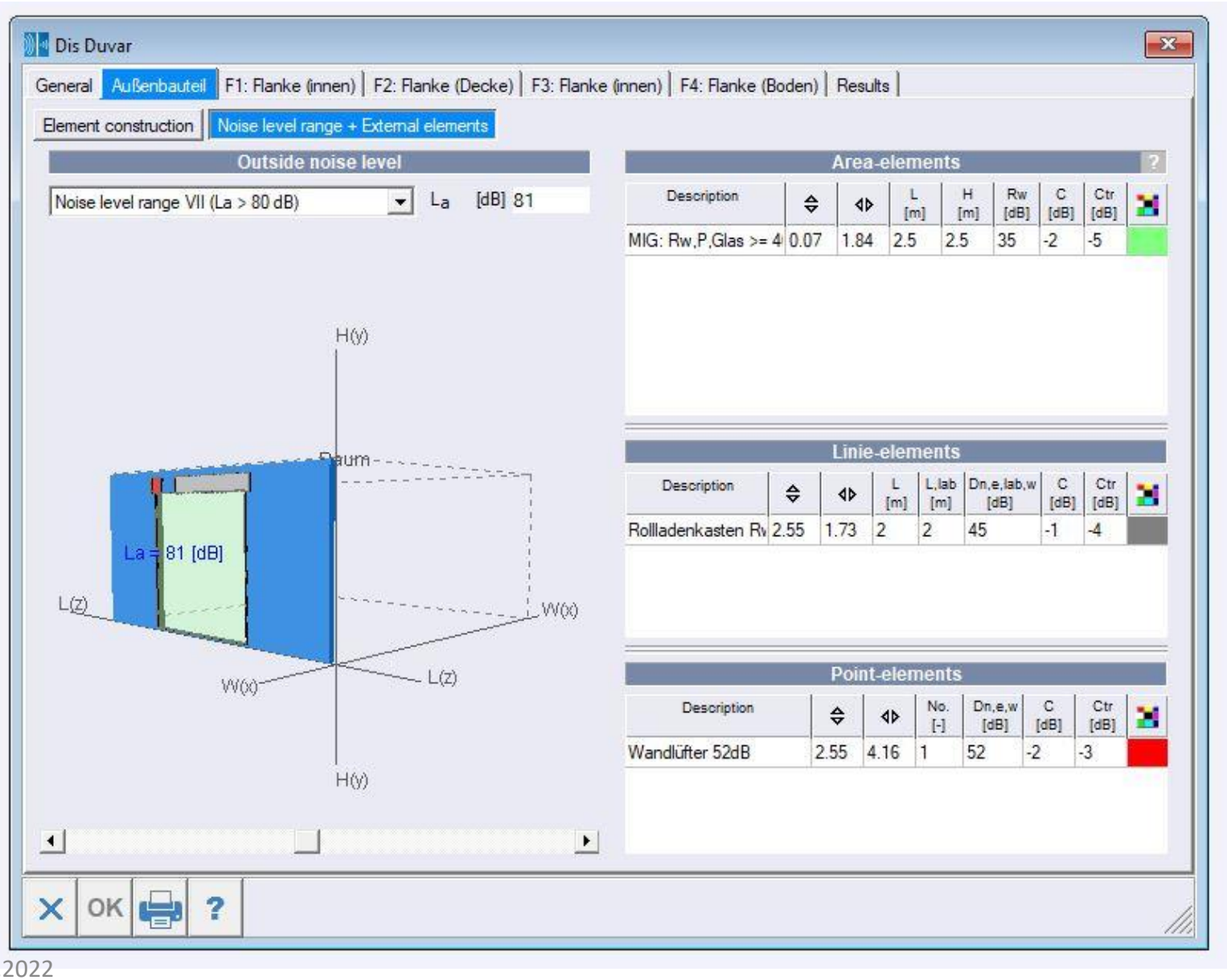



Dis Duvar
General
Außenbauteil
F1: Flanke (innen)
F2: Flanke (Decke)
F3: Flanke (innen)
F4: Flanke (Boden)
Results
External wall situation
>>>
Dis Duvar
External element with the highest noise level
F1: Flanke (innen)
F2: Flanke (Decke)
F3: Flanke (innen)
F4: Flanke (Boden)
Room
Name
Raum
Geometry
L [m]
W [m]
H [m]
6
6
3
Volume
V = 108.00 [m³]
External element
18.00 [m²] (area Ss: user input)
H(y)
F2
F3
La = 81 [dB]
F1
f1
L(z)
W(x)
F4
W(x)
L(z)
H(y)
Graphic settings
Graphic will be displayed as shown in the repor
OK

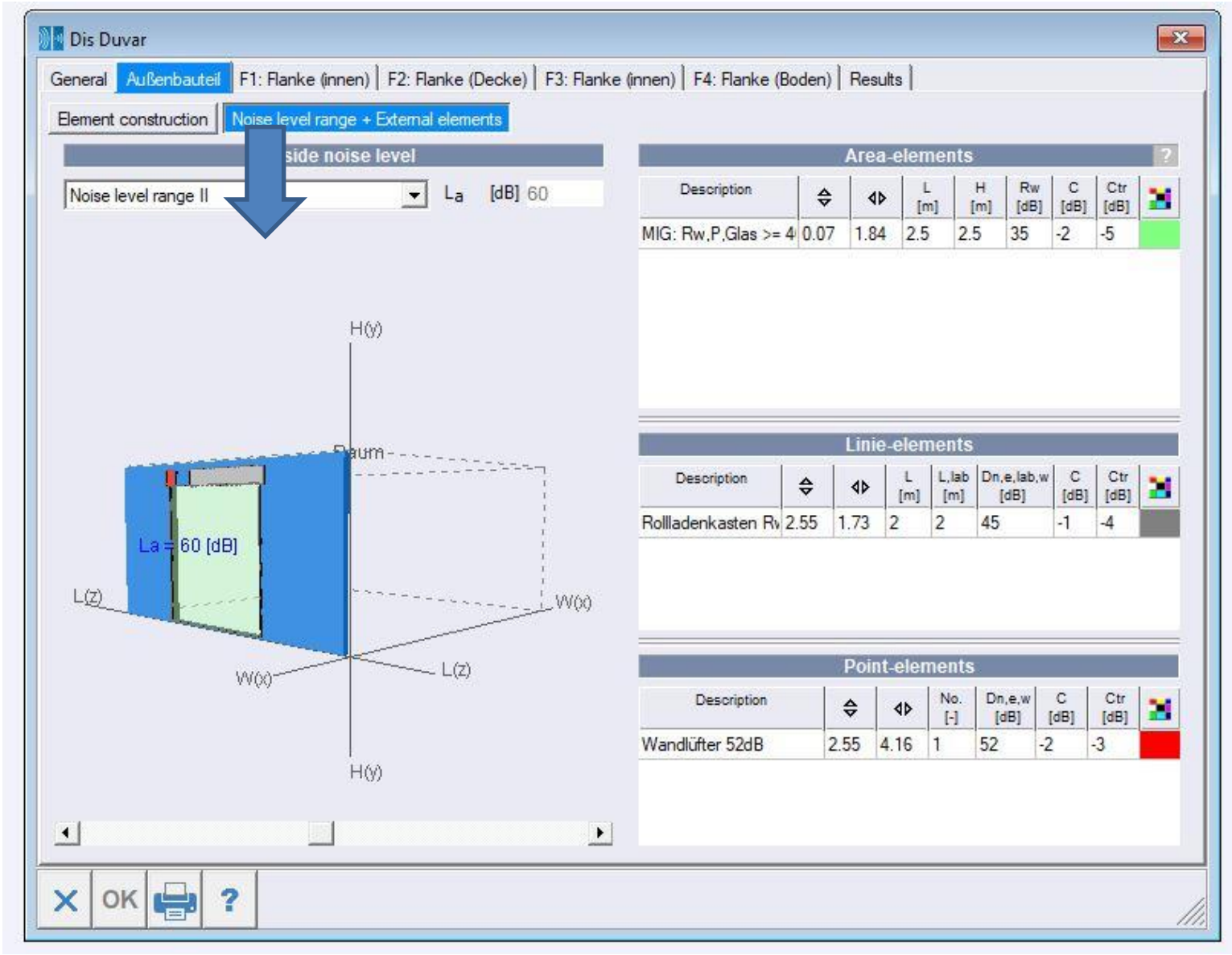
External Wall Elements



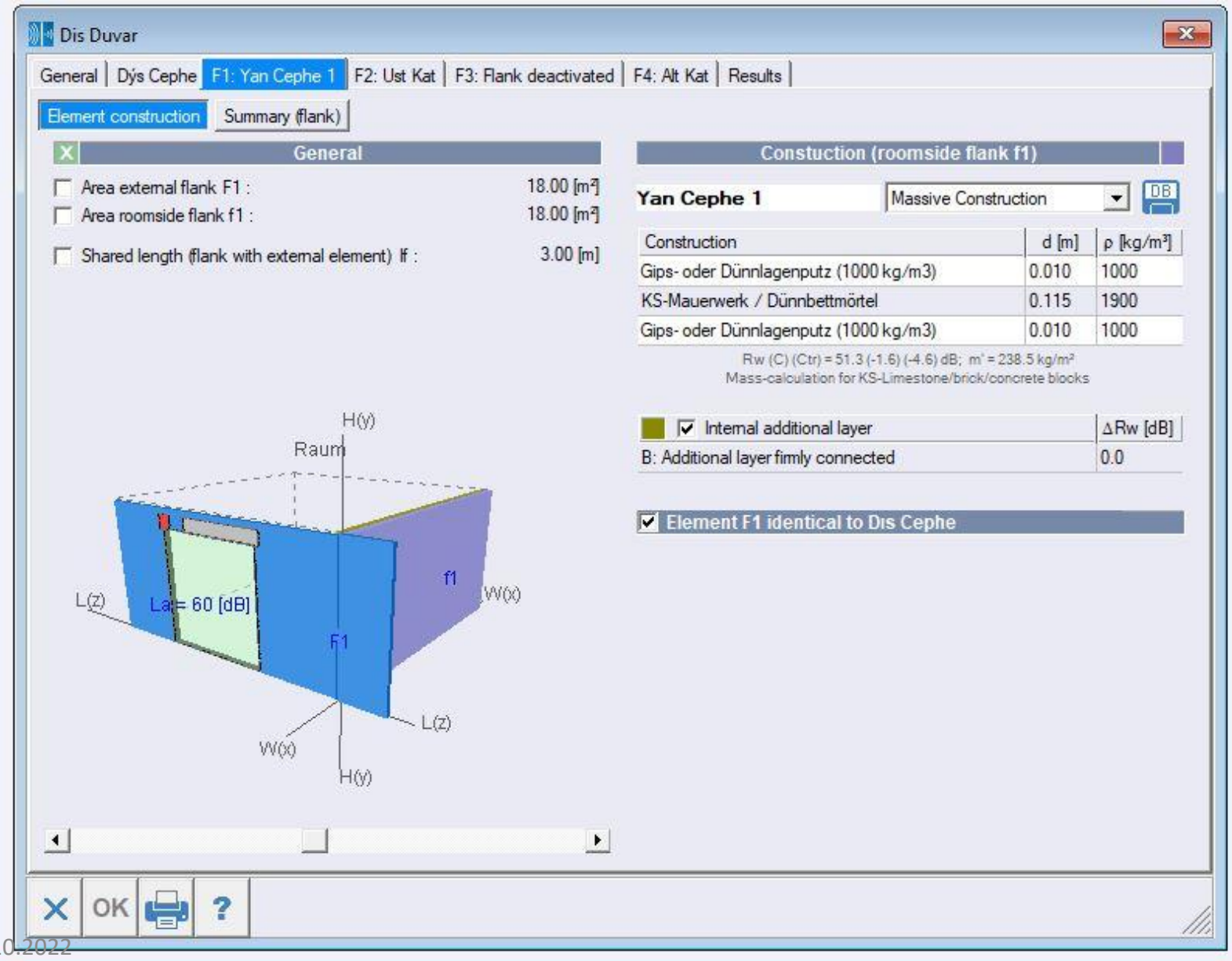
External Wall Elements



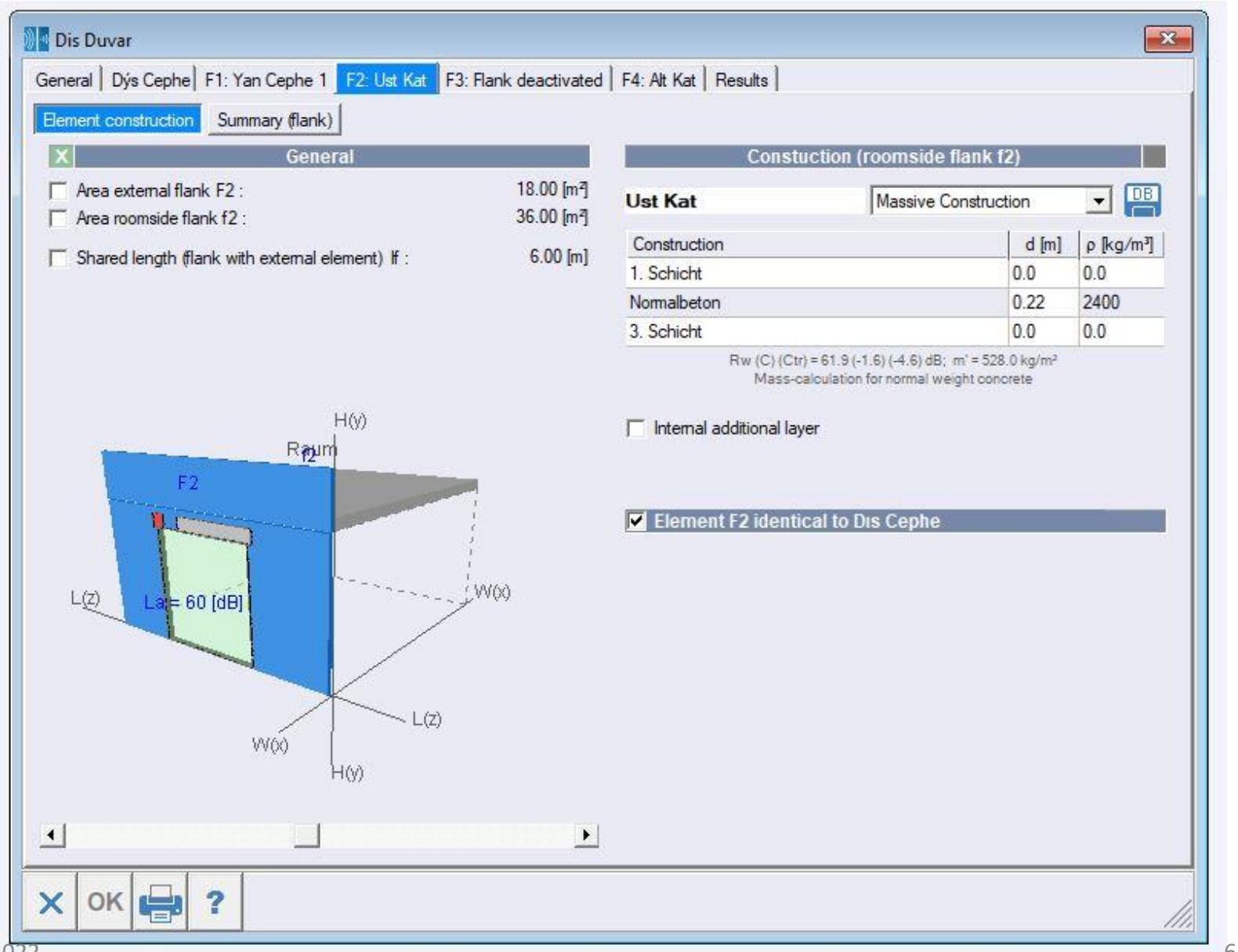
External Wall Elements and Noise Levels



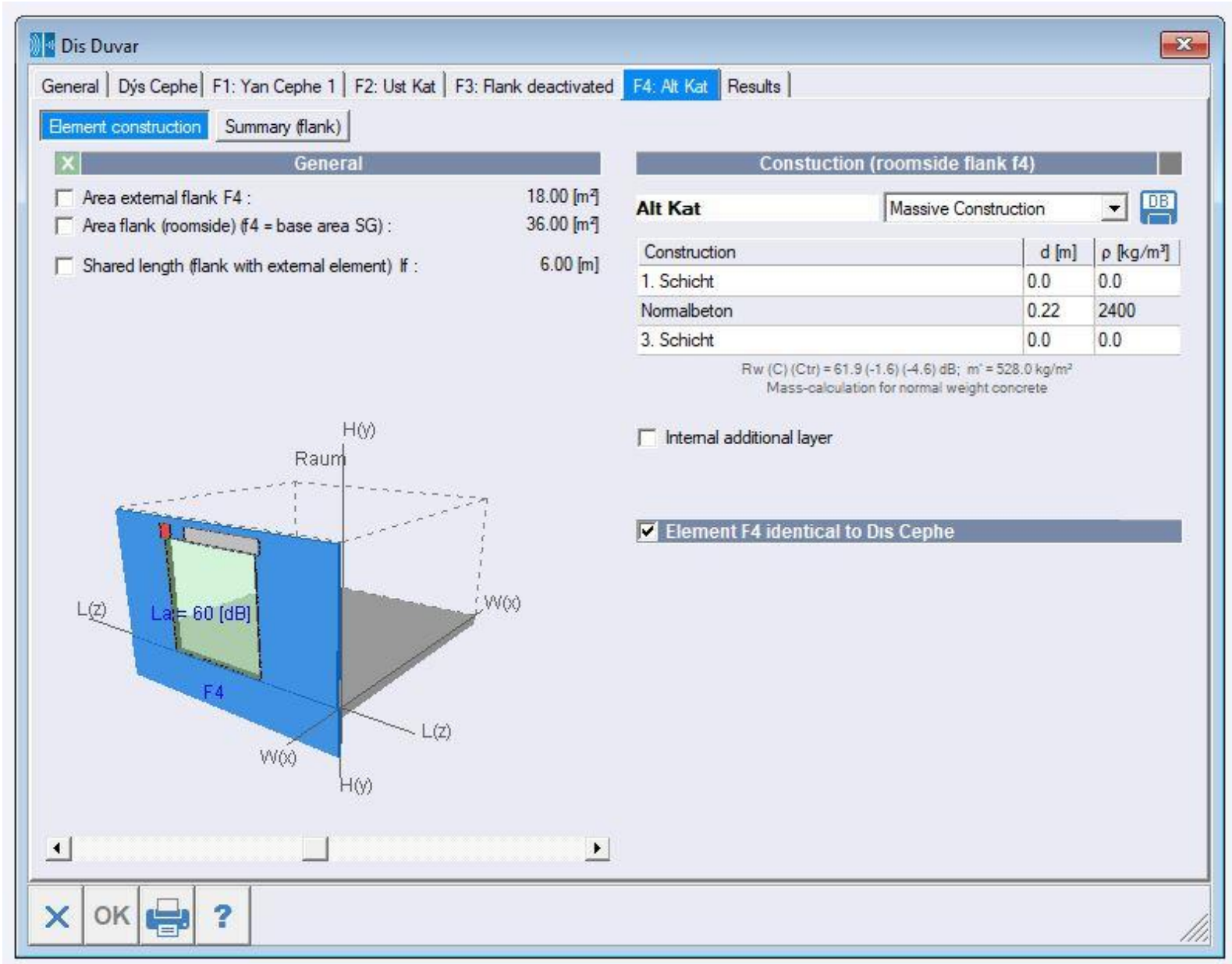
Side Facade 1



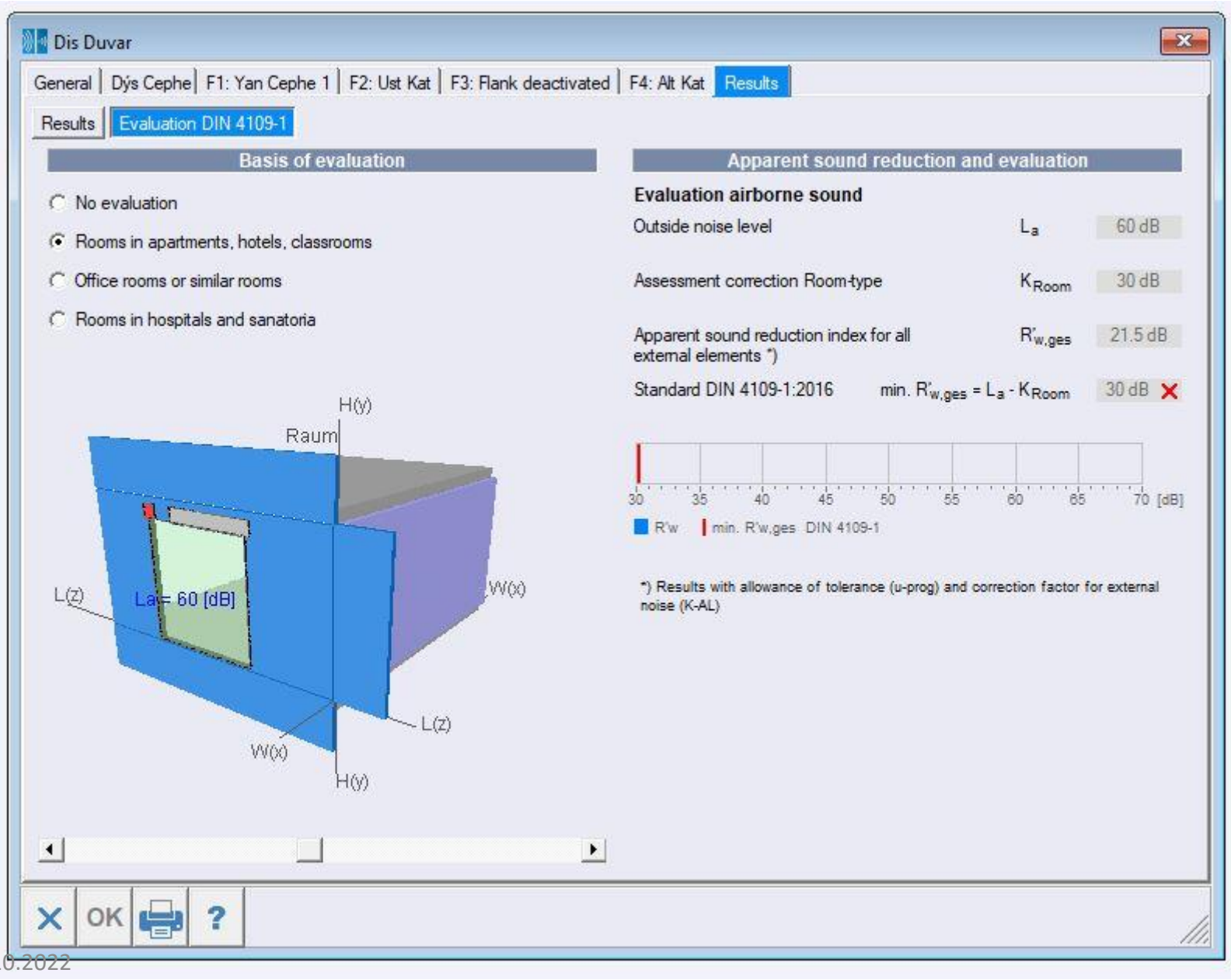
Upstairs


Dis Duvar
General
Dýs Cephe
F1: Yan Cephe 1
F2: Ust Kat
F3: Flank deactivated
F4: Alt Kat
Results
Element construction
Summary (flank)
General
Area external flank F2 : 18.00 [m²]
Area roomside flank f2 : 36.00 [m²]
Shared length (flank with external element) lf : 6.00 [m]
H(y)
Raum f2
F2
L(z)
Lat = 60 [dB]
W(x)
L(z)
W(x)
H(y)
Constuction (roomside flank f2)
Ust Kat
Massive Construction
DB
Construction | d [m] | ρ [kg/m³]
1. Schicht | 0.0 | 0.0
Normalbeton | 0.22 | 2400
3. Schicht | 0.0 | 0.0
Rw (C) (Ctr) = 61.9 (-1.6) (-4.6) dB; m' = 528.0 kg/m²
Mass-calculation for normal weight concrete
Internal additional layer
Element F2 identical to Dis Cephe
OK

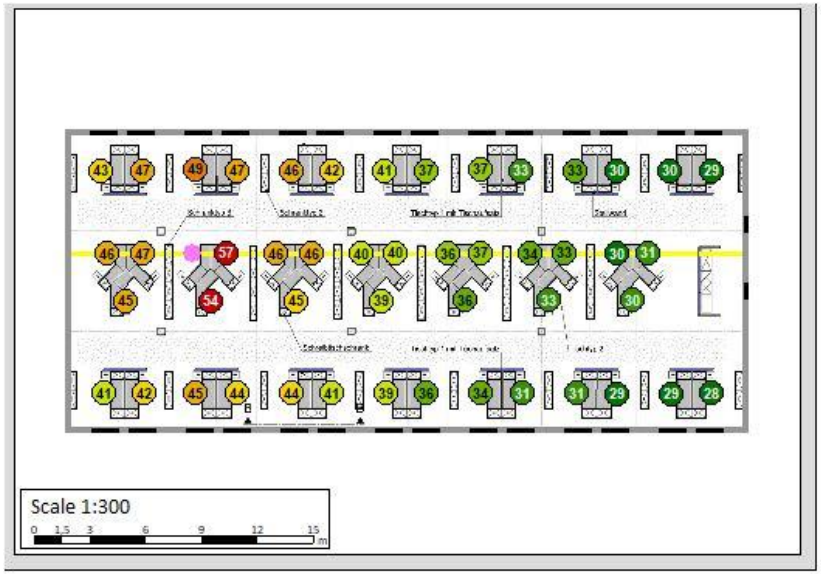
Downstairs

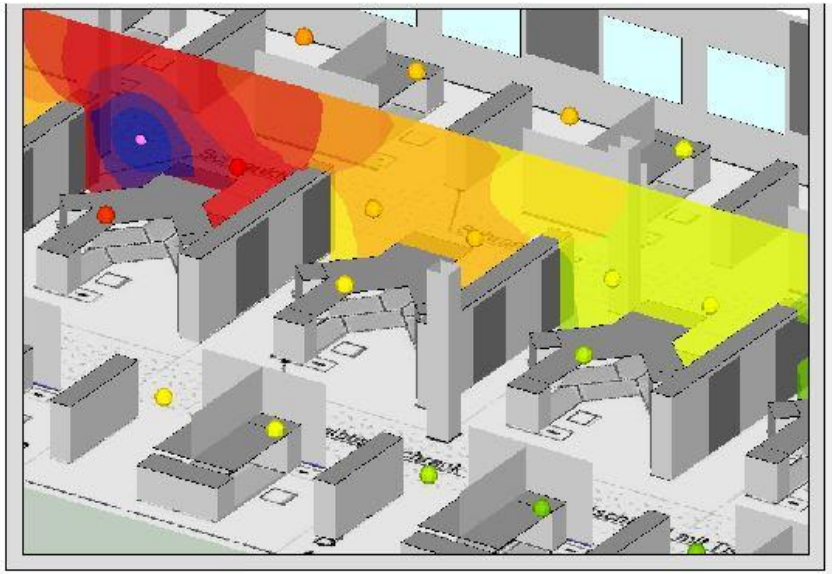

Dis Duvar
General
Dýs Cephe
F1: Yan Cephe 1
F2: Ust Kat
F3: Flank deactivated
F4: Alt Kat
Results
Element construction
Summary (flank)
General
Area external flank F4 : 18.00 [m²]
Area flank (roomside) (f4 = base area SG) : 36.00 [m²]
Shared length (flank with external element) lf : 6.00 [m]
H(y)
Raum
L(z)
La = 60 [dB]
W(x)
F4
L(z)
W(x)
H(y)
Constuction (roomside flank f4)
Alt Kat
Massive Construction
DB
Construction | d [m] | ρ [kg/m³]
1. Schicht | 0.0 | 0.0
Normalbeton | 0.22 | 2400
3. Schicht | 0.0 | 0.0
Rw (C) (Ctr) = 61.9 (-1.6) (-4.6) dB; m' = 528.0 kg/m²
Mass-calculation for normal weight concrete
Internal additional layer
Element F4 identical to Dis Cephe
OK
?

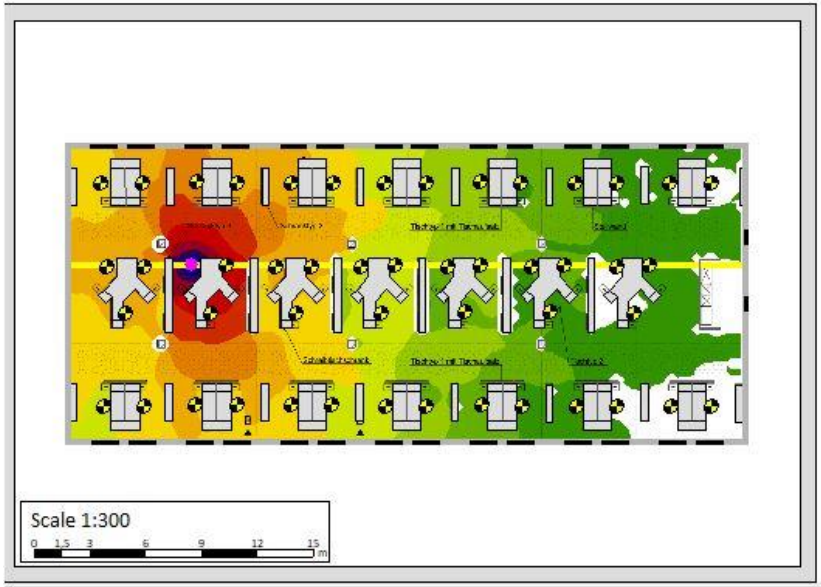
Results


Dis Duvar
General
Dýs Cephe
F1: Yan Cephe 1
F2: Ust Kat
F3: Flank deactivated
F4: Alt Kat
Results
Results
Evaluation DIN 4109-1
Basis of evaluation
No evaluation
Rooms in apartments, hotels, classrooms
Office rooms or similar rooms
Rooms in hospitals and sanatoria
H(y)
Raum
L(z)
La = 60 [dB]
W(x)
L(z)
W(x)
H(y)
Apparent sound reduction and evaluation
Evaluation airborne sound
Outside noise level
La
60 dB
Assessment correction Room-type
KRoom
30 dB
Apparent sound reduction index for all external elements *)
R'w,ges
21.5 dB
Standard DIN 4109-1:2016
min. R'w,ges = La - KRoom
30 dB
30
35
40
45
50
55
60
65
70
[dB]
R'w
min. R'w,ges DIN 4109-1
*) Results with allowance of tolerance (u-prog) and correction factor for external noise (K-AL)
OK
?

Open office example







Highlights industrial noise
Example: open plan office

Noise level
SPL
in dB(A)

30 <	<=	33
33 <	<=	36
36 <	<=	39
39 <	<=	42
42 <	<=	45
45 <	<=	48
48 <	<=	51
51 <	<=	54
54 <	<=	57
57 <	<=	60
60 <	<=	63
63 <		

Signs and symbols

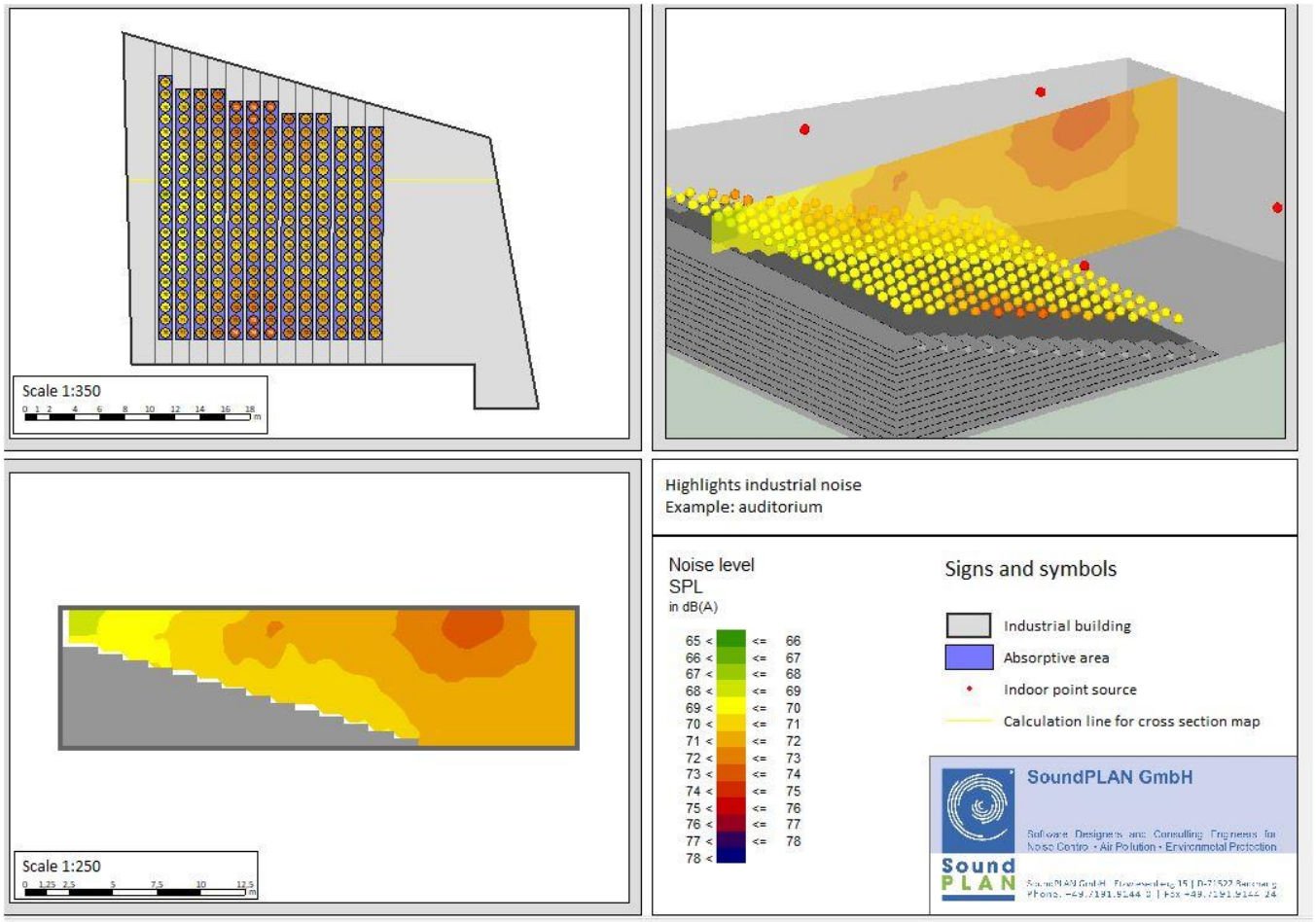
- Industrial building
- Absorptive area
- Indoor point source
- Calculation line for cross section map
- Transmissive area

SoundPLAN GmbH

Software, Designers and Consulting Engineers for Noise Control - Air Pollution - Environmental Protection

Sound PLAN

Concert/theatre/cinema hall example



Concert/theatre/cinema hall example