Urban Physics

wind, acoustics, insolation and precipitation

Study Guide

7S0X0, year 2020-2021
Version 2021-01-24

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0. Introduction

Academic year	2020/2021
Class planning / target audience	• Semester B Quartile 3 Building Physics: Building and Environment — Bachelor's degree program (year 2) — Compulsory, Dutch
ECTS credits BaMa	5
Provided by	• Department: the Built Environment • Sub-department: Unit Building Physics and Services (responsible)
Components of this subject	• 7S0X1 - Urban Physics - final test: written exam part 2 – open questions • 7S0X2 - Urban Physics - test I: assignment 1 • 7S0X3 – Urban Physics - test II: exam part 1 – multiple choice
Prior knowledge	For this course no specific prior knowledge is required
Follow-up subjects	• 7LS8M0 - Architectural Acoustics • 7LY7M0 – Techniques in Architectural Acoustics • 7LS9M0 – Heat, air, moisture / CFD 1 • 7LS6M0 – Heat, air, moisture / CFD 2 • 7LL1M0 – Sports & Building Aerodynamics
Lecturers	• prof.dr.ir. B.J.E. Blocken (responsible lecturer) • prof.dr.ir. M.C.J. Hornikx (co-lecturer) • dr. M.H.R. Cosnefroy (exercises)
Information	• prof.dr.ir. B.J.E. Blocken - VRT 6.30 - tel: 2138 - b.j.e.blocken@tue.nl • prof.dr.ir. M.C.J. Hornikx - VRT 6.17 - tel: 4236 - m.c.j.hornikx@tue.nl
EDUCATION AND EXAMINATION	
Type of education	• 8 weeks Q&A about recorded lectures (1 hour) • 8 weeks tutorials of 2 hour
Type of examination	• Interim examination – Written – Multiple choice - 30% of the final result • Final test – Assignment - 40% of the final result • Final test – Written – Open questions: 30% of the final result
Course material	**Acoustics:** - Sections from the book 'Urban noise pollution' by Murphy and King; - Sections from the various reports;

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	- All lecture notes **Wind, insolation and precipitation:** - Urban physics articles - All lecture slides
CONTENTS	
Learning objectives	· Gaining insight in urban physics processes such as wind, rain, air pollution, heat stress and the urban heat island effect; · Knowledge to take into account urban physics processes and related consequences in the design of buildings and cities; · Being able to assess wind discomfort problems in urban environments and to provide potential solutions to these problems; · To qualitatively describe the aspects that influence the urban sound environment, by using acoustic expressions; · To be able to identify and analyze urban sound environments of low quality, as well as to propose quantitative solutions; · To be able to calculate the sound level due to road traffic noise for simple urban situations;
Contents	Urban Physics deals with the way humans perceive the interaction between meteorological conditions and the urban environment, and how designers, planners and researchers can create buildings and cities that offer a high level of health and comfort. Therefore, this course is of the utmost importance for all designers, architects or urban planners, as well as for researchers. Research into health and comfort within buildings is often supported by the motivation that humans spend 90% of their time indoors. However, we also may expect a healthy and comfortable environment for the 10% that we spend outdoors. Moreover, an outdoor environment of poor quality (e.g. a high noise level or high level of air pollution) will often influence the indoor environment too. This course consists of lectures and a practical assignment. Lectures contain a theoretical part for the physical background as well as a part with case studies, a quiz and have an interactive character. The practical assignment is related to a wind comfort problem - identifying, analyzing and reporting of practical situations -, and related to noise - identifying and analyzing a practical situation as well as proposing improvements.

1. Planning of lectures, assignments and tests

The schedule of Urban Physics course can be found below. In Section 3, the detailed weekly programme can be retrieved.

	Contents	Type of education	Examination
Week 1, Monday	Building aerodynamics and wind comfort	Q&A about RL (1h)	
Thursday	Effects of noise, acoustic quantities	Q&A about RL (1h)	
Week 2, Monday	Wind-tunnel testing & Air pollution by particulate matter	&A about RL (1h)	
Thursday	Metrics of urban acoustics	Q&A about RL (1h), Tutorial (1h)	
Week 3, Monday	Self-study	&A about RL (1h)	
Thursday	Urban sound sources	Q&A about RL (1h), Tutorial (1h)	
Week 4, Monday	Wind-driven rain and wind energy	&A about RL (1h)	
Thursday	Effects on urban sound propagation	Q&A about RL (1h), Tutorial (1h)	
Week 5, Monday	Natural ventilation	Q&A about RL (1h)	
Thursday	Urban noise control	Q&A about RL (1h), Tutorial (1h)	
Week 6, Monday	Heat waves and urban heat island effect	Lectures (2h)	
Thursday	Computational urban acoustics, part I	Q&A about RL (1h), Tutorial (1h)	**IWE (1h)**
Week 7, Monday	CFD and sport stadium aerodynamics	Lectures (2h)	
Thursday	Computational urban acoustics, part II	Q&A about RL (1h), Tutorial (1h)	
Week 8, Monday	Oral presentation of assignment	Presentations (2h)	**HA**
Thursday	& Tips for written examination	Presentations (2h)	**HA**
Exam period		**Exam (3h)**	**FWE**

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Abbreviations
HA: Hand in the assignment
IWE: Intermediate written multiple-choice exam
FWE: Final written exam with open questions
RL: Recorded Lecture

Educational forms and teaching models:

Lectures
On Mondays, the lectures are related to acoustics and on Thursdays to wind, insolation and precipitation.

Tutorials
In the acoustics part, tutorials comprise half of the contact hours. Weekly, exercises are handed out related to the subject of the week. While working with these exercises, you are getting trained in the skills needed for the final written exam.

Deadlines:

Exam type	Group size	Deadlines	Submission
HA 1. Acoustics	2 students	Thursday 1 April, 13:30	m.h.r.cosnefroy@tue.nl
HA 2. Wind, insolation and precipitation	2 students		a.ricci@tue.nl
IWE	1 student	Thursday 25 March, 14:30 – 15:30	
FWE	1 student	Tuesday 6 April, 13:30 – 16:30	

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Abbreviations
HA: Hand in the assignment
IWE: Intermediate written multiple-choice exam
FWE: Final written exam with open questions

2. Programme by week (detail)

Week 1, Acoustics: Effects of noise, acoustics quantities

Course Material
- Lecture slides will be posted at Canvas
- Document 'Environmental noise pollution' Chapters 2-2.3, 3, 4-4.4.1, Box 4.1
- Document 'Burden of disease from environmental noise', p. viii-xvii

Background material:
- Document 'Environmental noise pollution' Chapters 1.1-1.3, 4.5
- Document 'Burden of disease from environmental noise', full document

Thursday 10 February Hour 5, Helix west 3.91
Lecture A.1 (Maarten Hornikx), Contents: Introduction, health effects of environmental noise, European noise mapping regulations.
Lecture A.2 (Maarten Hornikx), Contents: Acoustics quantities, acoustic pressure and velocity, sound pressure level, A-weighting, octave bands.

Week 1, Building aerodynamics and wind comfort

Course Material
- Lecture slides will be posted on Canvas after the lecture.
- Links to articles will be posted on Canvas after the lecture.

Monday 1 February, Hour 2, Canvas conference
Q&A session (Bert Blocken)
Recorded Lectures W.1-4, Contents:
1. Wind flow around buildings – I
2. Wind flow around buildings – II
3. Pedestrian-level wind – I
4. Pedestrian-level wind – II

Week 2, Acoustics: Metrics of urban acoustics

Course Material
- Lecture slides will be posted at Canvas
- Document 'Environmental noise pollution' Chapter 2.4

Background material:
- Document 'Environmental noise pollution' Chapter 2.5

Thursday 11 February Hour 5, Canvas conference
Q&A session (Maarten Hornikx)
Recorded Lecture A.3, Contents: Equivalent sound pressure level, Loudness, percentile levels, day-evening-night level.

Thursday 11 February Hour 6, Canvas Conference
Q&A session (Matthias Cosnefroy). Exercises on week 1 and week 2.

Week 2, Wind-tunnel testing & Air pollution by particulate matter

Course Material
- Lecture slides will be posted on Canvas after the lecture.
- Links to articles will be posted on Canvas after the lecture.

Monday 8 February, Hours 2, Canvas Conference
Q&A session (Bert Blocken)
Recorded Lectures W.7-9, Contents:
1. Wind-tunnel testing
2. Particulate matter – basics
3. Particulate matter removal in an urban area

Week 3, Acoustics: Sources of sound

Course Material
- Lecture slides will be posted at Canvas
- Urban Acoustics Reader week 3:
  - 'Environmental noise pollution' Chapter 5-5.1.2
  - 'Environmental noise pollution' Chapter 6.5

Thursday 25 February Hour 5, Canvas Conference
Q&A session (Maarten Hornikx)
Recorded Lecture A.4, Contents: noise sources in the urban environment, point, line and plane sources.
Thursday 25 February Hour 6, Canvas Conference
Q&A session (Matthias Cosnefroy). Exercises on week 3.

Week 3, Self-study

Week 4, Acoustics: Effects on noise propagation

Course Material
- Lecture slides will be posted at Canvas
- Document 'Environmental noise pollution' Chapter 2.6

Thursday 4 March Hour 5, Canvas Conference
Q&A session (Maarten Hornikx)
Recorded Lecture A.5, Contents: Explanation of acoustics assignment.
Ground effect, screening of sound, meteorological effects, façade reflections.

Thursday 4 March Hour 6, Canvas Conference
Q&A session (Matthias Cosnefroy). Exercises on week 4.

Week 4, Wind-driven rain and wind energy

Course Material
- Lecture slides will be posted on Canvas after the lecture.
- Links to articles will be posted on Canvas after the lecture.

Monday 1 March, Hours 2, Canvas Conference
Q&A session (Bert Blocken)
Recorded Lectures W.10-13, Contents:
1. Wind-driven rain – I
2. Wind-driven rain – II
3. Wind energy – I
4. Wind energy – II

Week 5, Acoustics: Urban noise control

Course Material

- Lecture slides will be posted at Canvas
- Document 'Environmental noise pollution' Chapter 7.3-7.5
- Document 'Novel solutions for quieter and greener cities', page 9-36

Thursday 11 March Hour 5, Canvas Conference
Q&A session (Maarten Hornikx)
Recorded Lecture A.6, Contents: Noise control at source and in propagation path

Thursday 11 March Hour 6, Canvas Conference
Q&A session (Matthias Cosnefroy). Workshop on urban noise mitigation.

Week 5, Natural ventilation

Course Material

- Lecture slides will be posted on Canvas after the lecture.
- Links to articles will be posted on Canvas after the lecture.

Monday 9 March, Hours 1 & 2, Canvas Conference
Q&A session (Twan van Hooff)
Recorded Lectures W.14-15, Contents:

1. Natural ventilation – Basics
2. Natural ventilation – Case study Amsterdam ArenA stadium

Week 6, Acoustics: Computing urban acoustics, part I

Course Material

- Lecture slides will be posted at Canvas
- Document 'Environmental noise pollution' Chapter 5,p. 138-140
- Document 'Cnossos', VI.2.3 up to and including VI.4.3.c

Thursday 18 March Hour 5, Canvas Conference
Q&A session (Maarten Hornikx)
Recorded Lecture A.6, Contents: Numerical modelling and ray acoustic modelling, calculation model for sound propagation, sound power calculation (Cnossosf), ground effect calculation. Explanation of use of noise mapping software.

Thursday 18 March Hour 6, Canvas Conference
Q&A session (Matthias Cosnefroy). Exercises on week 6.

Week 6, Heat waves and the urban heat island effect

Course Material

- Lecture slides will be posted on Canvas after the lecture.
- Links to articles will be posted on Canvas after the lecture.

Monday 15 March, Hours 1 & 2, Canvas Conference
Q&A session (Bert Blocken)
Recorded Lectures W.16-19, Contents:

1. Heat waves
2. The urban heat island effect
3. Modeling heat waves – case study Bergpolder Zuid
4. Reducing heat wave temperature: evaporative cooling

Week 6, Multiple-choice test
Thursday 19 March, Hour 5, Canvas Conference

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Week 7, Acoustics: Computing urban acoustics, part II

Course Material
- Lecture slides will be posted at Canvas
- Document 'Cnossos' VI.4.3.d and rest of section VI.

Thursday 25 March Hour 5, Canvas Conference
Q&A session (Maarten Hornikx)
Recorded Lecture A.7, Contents: Including façade reflections and meteorological effects in calculations.

Thursday 25 March Hour 6, Canvas Conference
Q&A session (Matthias Cosnefroy). Exercises on week 7.

Week 7, CFD and sport stadium aerodynamics

Course Material
1. Lecture slides will be posted on Canvas after the lecture.
2. Links to articles will be posted on Canvas after the lecture.

Monday 22 March, Hours 1 & 2, Canvas Conference
Q&A session (Bert Blocken)
Recorded Lectures W.20-24, Contents:
1. Why study 100 m aerodynamics?
2. Mathematical-physical model of running
3. Wind effects
4. Altitude effects
5. Stadium aerodynamics and sprint records

Week 8, Oral presentation of assignment, tips for written exam

Group A:
- Oral presentation of WIND assignment: Monday 30 March, 8:45 – 10:45, Canvas Conference
- Oral presentation of ACOUSTICS assignment: Thursday 2 April, 13:30 – 15:30, Canvas Conference

Group B:
- Oral presentation of ACOUSTICS assignment: Monday 30 March, 8:45 – 10:45, location t.b.d.
- Oral presentation of WIND assignment: Thursday 2 April, 13:30 – 15:30, location t.b.d.

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3. Assignments and tests

The final grade for this course is based on the following components:

Type of examination	Weight
a) Final - Assignment	40 %
b) Intermediate Written Exam	30 %
c) Final - Written Exam	30 %

To pass this course, the total score needs to be at least 5.5, the minimum score on the assignment needs to be at least 5, and the minimum score on the final written exam needs to be at least 5 on a total of 10. For the acoustics part of the written exam, a formula sheet will be handed out. This sheet will also be available at Canvas.

Note: the interim exam will cover the material from the first 5 weeks.

3.1. Assignment urban physics - wind

The assignment will be made in groups of 2 students. It consists of a wind tunnel study of pedestrian wind conditions around a group of buildings.

Actions:

1. Read this article: https://www-sciencedirect-com.dianus.libr.tue.nl/science/article/pii/S0167610597000457 to learn about the infrared thermography technique. Note: this link only works on the TU/e campus or using a VPN connection.
2. Attend the demonstration (example wind tunnel test) which is given for groups of 8 students.
3. Send the composition of your group to a.ricci@tue.nl. We will then assign you a building configuration to be tested.
4. Perform a wind-tunnel study with infrared thermography for the building group. Assistance will be provided by one of these two researchers: dr. Alessio Ricci and Anjali Krishnan. They will assist you in performing the measurements and help with taking the thermography images.
    a. Step 1: construct the building models so that they are as large as possible but with a blockage ratio below 5%.
    b. Step 2: measure the incident vertical profiles of mean wind speed and turbulence intensity.
    c. Step 3: calibration: measure the temperature distribution of the empty wind tunnel floor.
    d. Step 4: actual test: place building models in wind tunnel. Perform tests with different wind speed and at least three different wind directions. Allow thermography pattern to settle, take photograph from top.
    e. Step 5: postprocess the photographs to obtain contours of the temperature.
    f. Step 6: convert the contours of temperature to contours of amplification factor. A procedure on how to do that can be found here: https://www-sciencedirect-com.dianus.libr.tue.nl/science/article/pii/S0167610597000457. Note: this link only works on the TU/e campus or using a VPN connection.
    g. Step 7: compare the contours of amplification factor with those you will receive from dr. Alessio Ricci.
    h. Step 8: identify problematic areas where amplification factor is too high
    i. Step 9: adapt the building models with remedial measures (screens, canopies, vegetation, …) to reduce the amplification factor in the problematic areas

j. Step 10: actual test: place adapted building models in wind tunnel. Perform tests with different wind speed and the same three wind directions as in step d. Allow thermography pattern to settle, take photograph from top.
k. Step 11: postprocess the photographs to obtain contours of the temperature.
l. Step 12: convert the contours of temperature to contours of amplification factor. Interpret the results.

5. Write the report.
6. Give oral presentation of 10 minutes in week 8 of the course.

The written report and oral presentation should include:

1. **Description of building geometry and ABL flow:**
   a. Geometry of buildings: height, width, depth, spacing
   b. ABL flow: incident vertical profiles of mean wind speed and turbulence intensity

2. **Description of procedure followed.**
   a. Where wind speed measurements were performed
   b. How much time was needed to obtain settled temperature patterns
   c. How conversion of temperature patterns to patterns of amplification factors was performed

3. **Interpret results**
   a. Describe main features of the flow pattern that are visible from the contours of the amplification factors
   b. Explain the differences between the amplification factors that you determined and those you received from dr. Alessio Ricci.
   c. Identify problematic areas

4. **Suggestion of remedial measures**
   a. Suggest remedial measures to reduce amplification factor in the problematic areas
   b. Test these remedial measures in the wind tunnel.

5. **Interpret results**
   a. Describe main features of the flow pattern that are visible from the contours of the amplification factors
   b. To what extent are the remedial measures effective?

6. **Detailed self-reflection including at least:**
   a. Overview of specific items that the students learned from the course lectures and material
   b. Overview of specific items that the students learned from this assignment
   c. Overview of specific items that the students learned from the course lectures and material and that were used to perform the assignment

The report should have at least 10 pages of text followed by a series of figures. It should contain student names, numbers, code of course, table of contents, page numbers. The report should demonstrate knowledge of the course material, effort in addressing the above-mentioned components and care in reporting.

Evaluation criteria for the assignment include:

- Detail to which the situation is described
- Accuracy of wind-flow pattern assessment
- Effectiveness and feasibility of remedial measures
- Quality and completeness of interpretation of results
- Quality and completeness of self-reflection

- Correct referencing to literature and other sources
- Quality and clarity of figures (professional drawing (i.e. no hand drawings), care, precision, inclusion of north arrow, distance bars, …)
- Quality of English grammar and spelling
- Quality of the oral presentation: conciseness, completeness, clarity
- Clear demonstration of the knowledge from the course material by referencing to this material
- Overall effort and care in written and oral reporting

Reports shall be submitted in pdf by email to a.ricci@tue.nl at the latest on the day of the oral presentation of the report.

3.2. Assignment urban physics - acoustics

The assignment will be made in groups of 2 students.

The description of the assignment will follow shortly.

Reports shall be submitted in pdf by email to m.h.r.cosnefroy@tue.nl at the latest on the day of the oral presentation of the report

3.3. Written exam (interim) – multiple choice

The multiple-choice exam will consist of 20 questions about wind, insolation, precipitation and 20 questions about acoustics. Some example multiple-choice questions are given below:

1) **The logarithmic law indicates:**
    a. The variation of wind speed with height
    b. The variation of mean wind speed with height
    c. The variation of turbulence intensity with height
    d. The variation of mean turbulence intensity with height

2) **The area with the highest wind speed around an isolated block-type high-rise building is called:**
    a. The standing vortex
    b. The wake
    c. The stagnation region
    d. The corner streams

3) **In a passage between two buildings in converging V-shape, the amplification factor at pedestrian height is:**
    a. Equal to zero
    b. Between zero and one
    c. Equal to one
    d. Larger than one

4) **How much does the sound level decay with doubling the distance to a line source in free field?**
    a. 0 dB
    b. 3 dB
    c. 6 dB
    d. 9 dB

5) **What sound source are people most annoyed by?**
    a. Industry
    b. Road traffic
    c. Rail traffic
    d. Aircrafts

6) **The impedance *Z* of a porous outdoor ground surface is <u>not</u> dependent on:**
    a. The thickness of the ground material
    b. The flow resistivity of the ground material
    c. The frequency
    d. The angle of incidence of the sound wave

3.4. Written exam (final) – open questions

For the lectures by Bert Blocken (urban physics – wind), the written exam will consist of 3 questions extracted from a pre-defined list that is given at the end of this study guide.

3.4.1. List of questions to be prepared for the examination

The list with questions will be provided later. The answers to these questions should be prepared in advance and studied by the students, using the course material. The following guidelines apply for these answers:

- Answers should be complete, and answers to a single question most often should come **from different parts of the study material**.
- Answers should be well-structured.
- Answer should always be as complete as possible.
- Answers should demonstrate adequate and complete knowledge of the course contents.
- Whenever possible, answers **must include drawings and equations**.

3.4.2. Questions about the questions
Questions can be asked during and after the lectures. Students with additional questions can ask questions to the lecturer by email.

3.4.3. Material at the examination
No material can be used at the examination. Only a pen, a spare pen and a ruler are allowed.

4. Anti-plagiarism

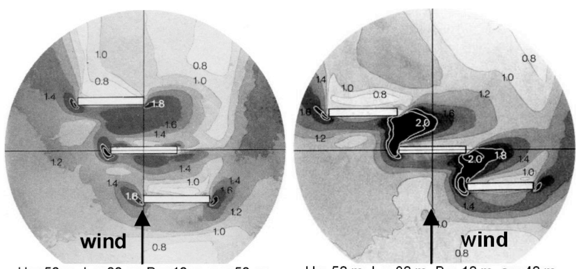
When you submit your assignment under your own name you are asserting ownership or that work. When using ideas of another person, you must give that person credit through appropriate referencing. Referencing serves multiple purposes: (i) it allows readers to further explore sources you have consulted, (ii) it shows the depth of your own thinking and process of inquiry, (iii) it allows you and your readers to compare and contrast your position with other people's positions, agreeing with some, disagreeing with others, and (iv) it gives proper credit to the hard work that many people have done before you.

In this course an electronic tool will be used, that will perform a check on whether pieces of text have been copied from other texts (either from other students or from internet sources).

Evidently, the above does not apply to the answers to the open questions in the written exam.

5. List of open questions for written exam on part “wind”

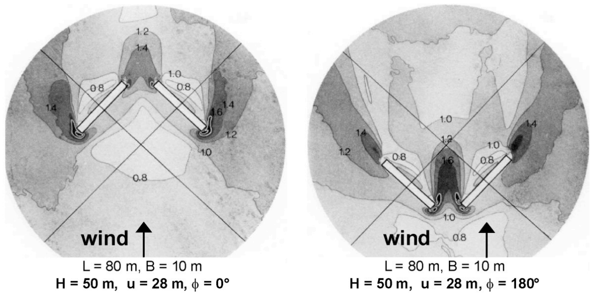
1. Make a drawing of the three-dimensional wind-flow pattern around a high-rise rectangular building and indicate and explain the main flow features. Which flow features are important for pedestrian wind conditions?
2. Explain the concept of flow separation. Why does flow separation always occur at sharp corners of an object? What is the physical reason?
3. Which three typical building configurations will almost always cause wind comfort problems? Provide a drawing and an explanation of how these configurations cause high wind speed at pedestrian level.
4. What is the definition of the Venturi effect in urban aerodynamics? Does the Venturi effect exist in passages between perpendicular buildings in a converging arrangement? Explain why or why not.
5. Describe in detail the figure below. How is this type of figure obtained? What are the numbers in this figure? Explain the difference between both figures, and the reasons for this difference.



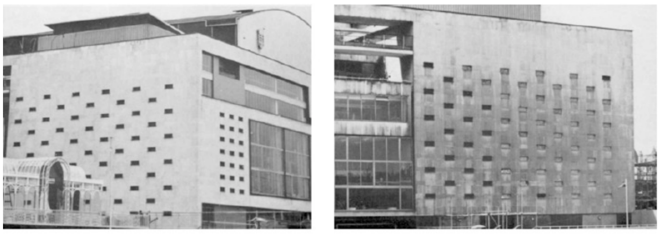
H = 50 m, L = 80 m, B = 10 m, s = 50 m
ϕ = 0° - buildings shifted 40 m

H = 50 m, L = 80 m, B = 10 m, s = 40 m
ϕ = 0° - buildings shifted 80 m

6. Describe in detail the figure below. How is this type of figure obtained? What are the numbers in this figure? Explain the difference between both figures, and the reasons for this difference.



7. Is the work of Giovanni Batista Venturi (1799) relevant for building aerodynamics and urban physics? Explain in detail.
8. What is a wind tunnel? Explain in detail the different wind-tunnel types and their advantages and disadvantages.
9. What are the main differences between an aeronautical and an atmospheric boundary layer wind tunnel?
10. What is wind-driven rain? Why is it important in building physics?
11. The figure below shows the Royal Festival Hall in London, after completion (left) and after a year of weather exposure (right). Explain in detail what happened here to cause this difference in appearance. Could this have been avoided, and if so, why, or why not?



12. Which assessment methods are available for wind-driven rain on buildings? What are their advantages and disadvantages?
13. Briefly explain the five steps that are used for CFD simulation of wind-driven rain on buildings.
14. What is the wind-blocking effect in wind-driven rain? How can it be explained?
15. What is the most beneficial type of a venturi-shaped roof for wind energy harvesting in the built environment? Explain why this type is better than other types. How much energy could be yearly obtained from a single wind turbine in such a roof (e.g. for Eindhoven location)? How much could be obtained from 10 wind turbines in the same roof? Is the latter 10 times as large as the yield of a single turbine, or not? And if so, why or why not?
16. Is the design of the Bahrain World Trade Center optimal from wind energy point of view? Explain your answer in detail by providing evidence whether or not it is optimal.
17. What are the main sources of particulate matter air pollution? What techniques are available to remove particulate matter from airstreams?
18. What type of strategies can be used to remove particulate matter by traffic from an urban area?
19. Provide the two driving forces for natural ventilation of buildings and indicate what can be done to enlarge the air exchange rate of a naturally ventilated building.

20. List the three ventilation assessment methods that are mentioned in the lecture and provide one advantage and one disadvantage of each method.
21. Choose the ventilation assessment method that is most suitable for the analysis of the natural ventilation flow in alternative configurations of the Amsterdam ArenA, and explain your choice.
22. Explain the influence of wind direction and urban surroundings on the natural ventilation flow through a building.
23. Name the seven physical reasons of the urban heat island effect as specified by Oke (1982) and provide an example for each of them.
24. Buildings in urban areas are expected to operate under warmer conditions in the future. Specify two factors which may contribute to higher temperatures in cities and describe them.
25. Explain advantages and disadvantages of the use of water spray systems for evaporative cooling in urban areas.
26. What is the urban heat island effect? Describe the main causes of the urban heat island effect (and of overheating of urban areas in general). How can this problem be mitigated?
27. Explain in detail how stadium wind flow patterns can affect records in the 100 m sprint. Can these effects be both positive and negative? If so, why? If not, why not?
28. How would you design a stadium to limit effects on sprint records? Consider different stadium geometries, and explain their advantages and disadvantages.
29. What is shown in Figure 2 below? How was this figure obtained? Explain in detail what happens if a sprinter runs from S to F.

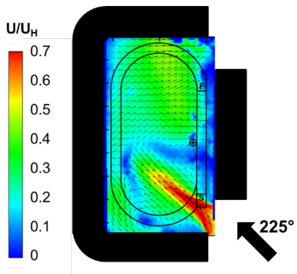


Figure 2.