MECH 5205
Building Performance Simulation
Course Outline

Instructor

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Building Performance Simulation

Building performance simulation (BPS) is an applied field of study focused upon improving the design and operation of buildings through the application of computational methods. It draws upon the disciplines of heat transfer, thermodynamics, fluid mechanics, mathematics, human behaviour, computational methods, and environmental sciences.

Aims

The aims of this course if for you to develop the necessary theoretical knowledge and practical skills to effectively apply BPS tools in design, analysis, and research contexts. Emphasis is placed upon simulating the building thermal and bulk airflow domains.

Teaching approach

This course is taught through a continuous learning cycle that includes the application of BPS tools in a series of structured exercises and guides students on methods for interpreting, scrutinizing, and verifying simulation predictions. The continuous learning cycle also emphasizes the study of the underlying models and simulation methodologies, including their inherent simplifications and limitations, through lectures and assigned readings. A detailed description of this learning approach is provided by Beausoleil-Morrison and Hopfe [2015, 2016b,a].

Through this teaching approach students will become cognizant of the impact of using BPS tool default methods and data, and the myriad sources of uncertainty. Students will experiment with BPS tools to investigate these impacts in a recursive manner with the formal teachings.

Intended learning outcomes

1. On completion of the course students should have developed knowledge and understanding of:
    - The physical models that have been developed and implemented into BPS tools for treating the significant heat and mass transfer processes.
    - The simplifications inherent in these models and the mathematical methods used to simulate them, and appreciate the necessity for these simplifications.
    - The relative importance of input data, the uncertainty associated with establishing these inputs, the potential for error propagation, and the impact this can have upon simulation predictions.

2. On completion of the course students should have developed the intellectual abilities to:
   - Realize the implications of these simplifications upon prediction accuracy and develop the ability to select appropriate models, simulation methods, and BPS tools for a given analysis.
   - Realize how BPS can be effectively employed in the building design process, and understand the limits of the technology.
   - Analyse, critically appraise, and solve simulation problems and generate, collect, and interpret numerical and/or qualitative data.
   - Identify their own learning needs, plan to meet these needs, and evaluate the learning outcomes.
3. On completion of the course students should have developed the practical skills to model and simulate the thermal and airflow performance of a building.

Course schedule

The class will meet twice weekly over the course of the term according the schedule posted on Carleton Central. Lectures will be given during these times and the assigned readings will be discussed, according to the schedule provided on Pages 6 through 10. These classes will also be used to demonstrate the use of BPS tools and to collectively examine the results of the simulation exercises and to diagnose problems through simulation autopsies [Beausoleil-Morrison and Hopfe, 2016a].

Reference materials

There is no required text for this course. Readings from journal articles, conference papers, and book extracts will be assigned for each of the lecture topics outlined on Pages 6 through 10. Most of these materials will be available through the Carleton Library or freely available on the web; materials will be posted on cuLearn when this is not the case.

Screen-capture videos illustrating the operation of BPS tools will posted on cuLearn. These will be indispensable aids to support the coursework and your active learning.

The following books have been placed on reserve at the Carleton Library as students may find these useful supplementary material:

- J.A. Clarke (2001), Energy Simulation in Building Design, 2nd Edition, Butterworth Heinemann, ISBN 0-7506-5082-6.
- J.L.M. Hensen and R. Lamberts (2011), Building Performance Simulation for Design and Operation, Spon Press, ISBN 978-0-415-47414-6.

Coursework

Students will perform a series of structured exercises that have been developed to support the teaching of theory. Each exercise will be performed in parallel to the lectures and assigned readings according to the schedule provided on Pages 6 through 10. For example, a lecture on convective heat transfer at internal surfaces will be given during the 9th class. The assigned readings associated with this topic will be discussed during the 10th class. Students will submit the results of the simulation exercise on convective heat transfer at internal surfaces the day prior to the 11th class, during which the results will be collectively analyzed with a simulation autopsy.

You will use both the ESP-r and EnergyPlus BPS tools in conducting these exercises. Results will be submitted in a standard format. These exercises must be conducted on an individual basis. Late submissions will not be accepted and a grade of zero will be assigned, without exception.

You will gain an understanding of the methods used to simulate individual heat and mass transfer processes through these exercises. You will also develop skills at applying BPS tools and extracting results, and will develop an appreciation for the sensitivity of predictions to input data and modelling options. This knowledge will be integrated through the final assignment during which you will apply one of these BPS tools to predict the thermal performance of the Urbandale Centre for Home Energy Research (CHEeR) research house.

A separate brief will be provided that details the requirements of this assignment.

As with the simulation exercises, this assignment must be conducted on an individual basis and late submissions will not be accepted.

Final exam

The final exam will be scheduled by the university during the final exam period. This will be a closed-book examination that draws mainly upon material presented during the lectures and from the assigned readings.

Level of effort

The following table provides guidance on the level of effort expected to successfully complete the course.

In-class contact time and final exam	40 hours
Assigned readings	20 hours
Simulation exercises	45 hours
Integrative assignment	35 hours

Marking scheme

Simulation exercises	40%
Integrative assignment	35%
Participation during in-class discussions of assigned readings	5%
Final exam	20%

Class topics

Class #	Chapter	Topic
1	1	**Introduction** - Introduction to BPS. - Review course outline and teaching approach. - Discussion of first simulation exercise (the *base case*). - Demonstration of ESP-r (geometry, constructions, boundary conditions).
2	1	**History of BPS** - Demonstration of ESP-r (operations, controls, running simulations, results analysis). - Historical developments in BPS. - Overview of some major BPS tools.
3	1	**Validity of BPS** - Review progress on creation of *base case* in ESP-r. - Calibration, validation, and verification techniques. - Demonstration of EnergyPlus (geometry, materials, constructions).
4	2	**Energy and mass transfers within buildings** - Discussion of first assigned readings. - Energy and mass transfers within buildings. - The thermal zone. - Subdivision of buildings into thermal zones. - Energy and mass balances on zone air volumes. - Demonstration of EnergyPlus (internal heat gains, air infiltration, basic heating systems, surface convection).
5	1	**Simulation exercise progress review** - Review progress on creation of *base case* in ESP-r and EnergyPlus. - Methods for scrutinizing simulation predictions.
6	2	**Energy and mass transfers within buildings (continued)** - The energy balance for internal surfaces. - Methods for resolving zone energy balances.
7-8	1	***Base case* results** - Simulation autopsy of *base case*. - The impact of simulation time-step.

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Class #	Chapter	Topic
9	3	**Convective heat transfer at internal surfaces** - Discussion of assigned readings on energy and mass transfers within buildings. - Autopsy of simulation exercise on energy and mass transfers within buildings. - Convective heat transfer basics. - Convective regimes within buildings. - Modelling convection heat transfer at internal building surfaces.
10	4	**Internal heat gains and moisture sources** - Discussion of assigned readings on convective heat transfer at internal surfaces. - Sources of heat and moisture gains in buildings. - Prescribing internal heat gains and moisture sources. - Modelling occupant behaviour.
11	5	**Solar heat gains at internal surfaces** - Discussion of assigned readings on internal heat gains and moisture sources. - Autopsy of simulation exercise on convective heat transfer at internal surfaces. - Solar radiation basics. - Solar irradiance in the indoor environment. - Predicting the distribution of solar irradiance to interior surfaces.
12 - 13	6	**Longwave radiation exchange between internal surfaces** - Discussion of assigned readings on solar heat gains to interior surfaces. - Autopsy of simulation exercise on internal heat gains and moisture sources. - Longwave radiation heat transfer basics. - Modelling radiation exchange between surfaces within a zone. - Radiation exchange between surfaces. - View factors. - Autopsy of simulation exercise on solar heat gains to interior surfaces. - Brief for integrative assignment.

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Class #	Chapter	Topic
14	7 & 8	**Energy transfer at external surfaces and weather data** - Discussion of assigned readings on longwave radiation exchange. - Energy transfers at external building surfaces. - Representative climate data. - Historical climate data. - Predictive climate data. - Autopsy of simulation exercise on longwave radiation exchange.
15 - 16	9	**Solar irradiance on exterior building surfaces** - Discussion of assigned readings on weather data. - Predicting direct beam solar irradiance on tilted surfaces. - Modelling sky diffuse solar radiation. - Modelling ground-reflected solar radiation. - Shading by building elements and surrounding objects. - Autopsy of simulation exercise for energy balances at external surfaces. - Autopsy of simulation exercise on weather data.
17	10	**Convection heat transfer at external surfaces** - Discussion of assigned readings on solar irradiance on exterior building surfaces. - Autopsy of simulation exercise on solar irradiance on exterior building surfaces. - Modelling convection heat transfer at external building surfaces. - Discussion of simulation strategies for integrative assignment.
18	11	**Longwave radiation heat transfer at external surfaces** - Discussion of assigned readings on convection heat transfer at external surfaces. - Modelling longwave radiation exchange at external building surfaces. - Predicting effective temperatures of radiation sinks (sky and ground). - Demonstration of representing multi-zone buildings in ESP-r and EnergyPlus.

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Class #	Chapter	Topic
19	12	**Heat transfer between buildings and the ground** - Discussion of assigned readings on longwave radiation heat transfer at external surfaces. - Autopsy of simulation exercise on convection heat transfer at external surfaces. - Simplified methods for approximating heat transfer between buildings and the ground. - Detailed modelling of heat transfer between buildings and the ground. - Demonstration of ground heat transfer models in ESP-r and EnergyPlus.
20 - 21	13	**Transient conduction heat transfer through opaque envelope components** - Discussion of assigned readings on heat transfer between buildings and the ground. - Autopsy of simulation exercise on longwave radiation heat transfer at external surfaces. - Response function method. - z-transfer function method. - Determining conduction transfer functions. - Numerical methods (finite difference/finite volume). - Advantages and limitations of each method. - Strategies for dealing with thermal bridging. - Autopsy of simulation exercise on heat transfer between buildings and the ground.
22	14	**Heat transfer through windows and doors** - Discussion of assigned readings on transient conduction heat transfer. - Autopsy of simulation exercise on transient conduction heat transfer. - Modelling solar absorption, reflection, and transmission. - Modelling convection heat transfer within glazing unit. - Modelling longwave radiation heat transfer processes. - Modelling blinds and other window coverings. - Review progress on integrative assignment.

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Class #	Chapter	Topic
23 -24	15	**Infiltration and inter-zone airflow** - Discussion of assigned readings on heat transfer through windows and doors. - Single-zone methods for predicting air infiltration. - Network airflow methods for modelling ventilation and infiltration. - Computational fluid dynamics for resolving room airflow patterns. - Modelling natural and hybrid ventilation systems. - Autopsy of simulation exercise on heat transfer through windows and doors. - Review progress on integrative assignment.
25		**Integrative assignment results** - Discussion of assigned readings on infiltration and inter-zone airflow. - Autopsy of simulation exercise on infiltration and inter-zone airflow. - Presentation of simulation predictions for integrative assignment. - Collective diagnosis of discrepancies between simulation predictions and measurements. - Closing remarks and future learning.

References

Ian Beausoleil-Morrison and Christina Hopfe. Teaching building performance simulation through a continuous learning cycle. In *Proc. Building Simulation 2015*, Hyderabad, India, 2015.

Ian Beausoleil-Morrison and Christina J Hopfe. Teaching building performance simulation: ever done an autopsy? In *Proc. Building Simulation and Optimization 2016*, Newcastle, UK, 2016a.

Ian Beausoleil-Morrison and Christina J Hopfe. Developing and testing a new course for teaching the fundamentals of building performance simulation. In *Proc. eSim 2016*, pages 22–33, Hamilton, Canada, 2016b.