URBAN CLIMATE & ENERGY DEMAND IN BUILDINGS

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ZUSAMMENFASSUNG

The project deals with the modelling of urban microclimate in street canyons and urban neighbourhoods taking into account in particular combined effects of wind and solar radiation. Modelling and simulation are performed using both building energy simulation (BES) and computational fluid dynamics (CFD) techniques. Validation experiments in selected isothermal and non-isothermal cases are undertaken (air flow patterns, temperature distributions) in the Empa/ETH atmospheric boundary layer wind tunnel. With the enhanced understanding of the flow and heat transfer phenomena and the respective models developed, the impact of the urban climate on daytime and night-time (passive cooling) ventilation potentials as well as on heating and cooling demand of buildings are investigated.

In the present phase of the project, BES and CFD simulations were performed for typical street canyon situations. Methods to reduce the computational demand for the CFD simulations are crucial for coupled simulations. Therefore customized wall function modelling was developed and applied, thus better allowing for coupled BES-CFD simulations. A wind tunnel street canyon model with heated walls was constructed and is presently used for time-resolved flow experiments in the wind tunnel using the particle image velocimetry system, for both forced and mixed convection (considering buoyancy along the heated building façades). Measured results were compared with results from CFD simulations. Furthermore the analysis of urban heat island (UHI) effect on heating and cooling degree days was completed. Major drivers for UHI effects for seasonal and diurnal patterns, and possible measure to mitigate such effects were identified.

In the year 2012, the wind tunnel tests will be continued and BES-CFD coupled simulations will be performed for typical street canyon situations. The results will then be used to quantify the energy impact of urban morphology and UHI effects for a number of configurations. The results of the project will be published in a PhD thesis, at conferences, and in scientific journal articles.

Projektziele

The project aims at further developing the basic knowledge of physical processes which are relevant for urban microclimates. On the street canyon and on the urban neighbourhood level microclimatic processes shall be analyzed from the point of view of energy demand in buildings.

Modelling and simulation knowledge as well as prediction capabilities of computer models shall be enhanced in order to predict consequences of planned buildings and urban development on the microclimate. The impact of urban climate on daytime and night-time (passive cooling) ventilation potentials as well as on heating and cooling demand of buildings shall be investigated and quantified.

Today's building energy models are designed for stand-alone buildings. Combining local urban climate modelling by computational fluid dynamics (CFD) with building energy simulation (BES) models allows for more accurately predicting the energy demand of buildings in cities, but also the local outdoor climate. Local velocities and air temperatures, and heat exchange due to convection and radiation at the building facades, are to be considered.

The project milestones are: (i) modelling of flow and heat transfer by CFD simulation for microclimates in street canyons and urban areas; (ii) wind tunnel experiments with selective empirical validation; (iii) analysis of urban heat island (UHI) effects on heating and cooling demand; (iv) definition of typical quarter morphologies of Swiss cities; (v) assessment of the urban climate impact on building energy demand.

The results of the project are a methodology and the respective models to assess the impact of an urban building configuration on the local microclimate and to gain insight in the mechanisms and the impacts of the urban climate on the energy demand in buildings.

Durchgeführte Arbeiten und erreichte Ergebnisse

Case study situations: A first overview on existing work regarding urban morphology in relation to numerical and experimental urban climate studies was made. The analysis showed that in Switzerland there are only a few cities where UHI effects are not superimposed by other microclimatic and topographic effects. For all of these cities, quite similar urban city quarter morphology types can be specified. In the following, work focused on the city of Basel, as for this city detailed data on UHI effects and urban boundary layer flow is available from the *BUBBLE* project [1]. For Basel, a list of building and quarter parameters was established by a comprehensive on site inspection tour for four typical quarters, representing the four city quarter types specified, and having a link to the *BUBBLE* measurement sites.

Analysis of UHI effect on heating and cooling demand: Based on this data, a comprehensive analysis of the urban heat island (UHI) effect on heating and cooling degree days was completed. Major drivers for UHI effects for seasonal and diurnal patterns, and possible measure to mitigate such effects were identified. The results of this study are documented in a separate report [2].

Flow and heat transfer modelling: For the coupling of CFD (*Fluent*) and BES (*TRNSYS*) models, methods to reduce the computational demand for the CFD simulations are crucial [3], [4]. Therefore, our work focussed on determining the effects of different modelling approaches of the near wall region at the building envelope and thus on the convective heat transfer coefficients (CHTC) (low-Reynolds number modelling, standard wall functions, adaptive wall functions [5]). In addition the influence of time resolved modelling on the ventilation of street canyons was analysed by comparing results of large eddy simulations (LES) with Reynolds averaged Navier-Stokes (RANS) methods and with experimental data. The results clearly indicated the importance of unsteadiness on the exchange fluxes, as predicted by LES [6], [7], [8].

Impact on heating and cooling demand: With the modelling tools established, the impact on a street canyon configuration and of urban heat island intensities was analysed for a number of different building types. The results show significant differences to the traditional stand-alone building analysis, see figure 1 and [9], [10].

Experimental evaluation: Many of the problems in regard to the set-up of the particle image velocimetry (PIV) system in the Empa/ETH atmospheric wind tunnel could be solved. First tests for street canyon configurations were conducted [11]. A modular street canyon model was constructed which allows to heat the different wall and ground surface elements to individual surface temperature set-points. The built-up of this model was quite delayed, nevertheless first tests in the wind tunnel could now be conducted and were very promising, see figure 2.

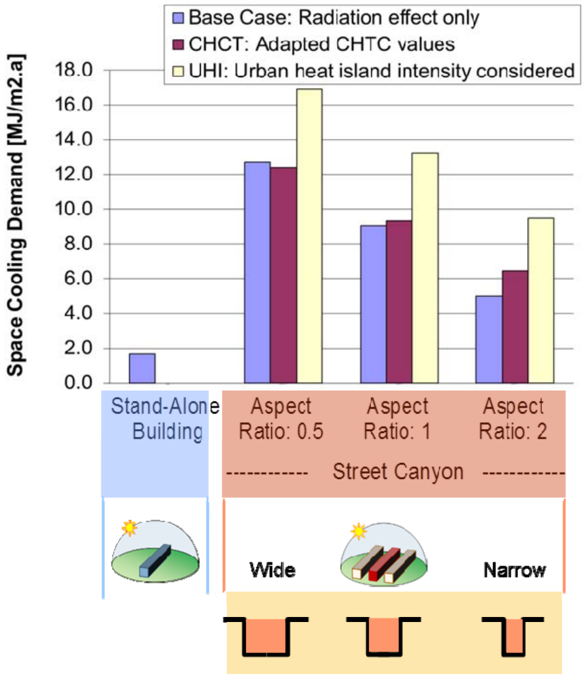

Fig. 1: Annual space cooling demand for different modelling cases and different street canyon aspect ratios.

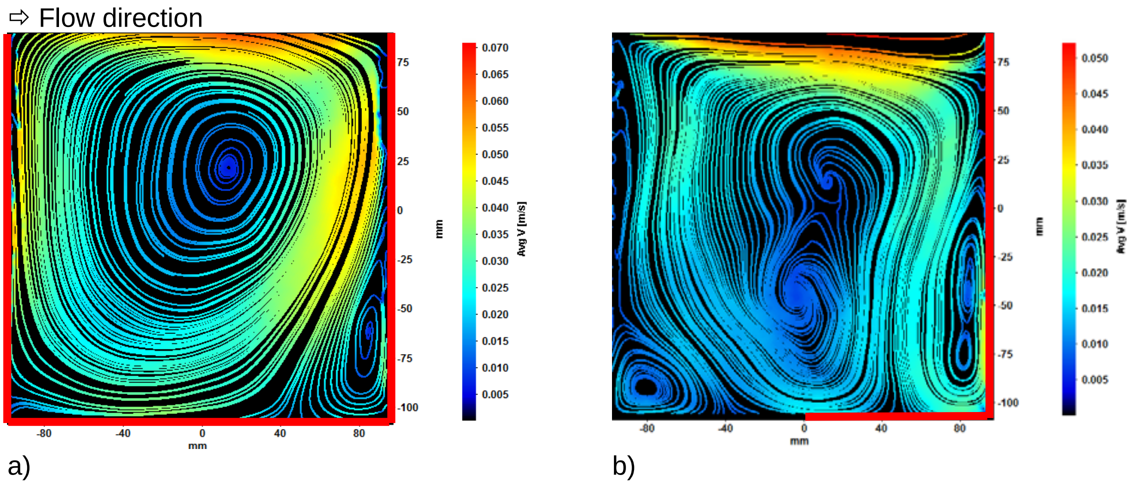

Fig. 2: Streamlines of the flow pattern in a street canyon measured in the Empa/ETH wind tunnel by 2D PIV for (a) both walls and ground heated; (b) only windward wall and right side of ground heated.

Publications: Results of the modelling work related to this project were presented at ICWE13 (13^{th} Int. Conference on Wind Engineering) [8], [10]; at Physmod 2011 (International Workshop on Physical Modelling of Flow and Dispersion Phenomena) [7], [11]; and at CISBAT11 (Int. Conference on Clean-Tech for Sustainable Buildings) [9]. Results of the work were also published in SCI/SCIE cited scientific journals [5],[6]. Additional papers were submitted and are presently in review.

Nationale Zusammenarbeit

Inherently, a close collaboration is established with the Chair of Building Physics at ETHZ, being also the link to the activities of the ETHZ Energy Science Center (ESC). Together with EPFL-LESO (Prof. Scartezzini) and ETHZ-SuAT (Prof. Schlüter) a closer collaboration in the field of urban multiscale energy modelling is envisaged in the frame of CCEM and NFP. Contacts exist also to Prof. Schär (ETHZ) and Prof. Parlow (Uni Basel) for climate modelling issues.

Internationale Zusammenarbeit

Collaboration with University of Cyprus (UCY) (Prof. M. Neophytou) was established in regard to experimental and CFD validation. UCY runs a PIV system quite a similar to the one at Empa, but in a water tunnel, and as a 3D tomographic PIV system with 4 cameras. Empa was instrumental to make this system operational. Supplementary tests in respect to mixed convection in street canyons are planned. Outside this project, Empa/ETH also participated in field tests in respect to the influence of evapotranspiration on urban street canyon climate.

Close collaboration is established with T. Defraeye (KU Leuven) and Prof. B. Blocken (TU Eindhoven) in respect to CFD modelling of heat transfer at building facades, with the Los Alamos National Laboratory (USA) for meso-scale LES CFD modelling, with Concordia University (Ca) and Prof. M. Santamouris (U of Athens) for UHI mitigation measures.

With the wind tunnel now in operation, contacts to other institutions operating atmospheric boundary layer wind tunnels and PIV equipment were intensified, namely with U of Hamburg (D) (Prof. M. Leitl), U of Western Ontario (Ca) (Prof. E. Savory), EC Nantes (F) (L. Perret); CSTB Nantes (F) (P. Delpeche), U of Sydney (Aus) (S. Cochard).

Elements and first results of this project were also presented by Prof. J. Carmeliet at several occasions, e.g. at the Int. Conf. on Smart Energy Strategies [12].

Bewertung 2011 und Ausblick 2012

Case study situations: Basler & Hofmann AG as the project partner focussing on city morphologies and evaluation of UHI effects has completed its project involvement by end March 2011. As mentioned, the results of the analysis of UHI effect on heating and cooling demand are documented in a separate report [2].

Numerical modelling: Methods for the coupling of CFD (*Fluent*) and BES (*TRNSYS*) and the analysis of different modelling approaches of the near wall region were further developed and published. The work to predict the cooling demand of stand-alone buildings and buildings in a street canyon for typical time periods will be extended, and conducted by coupled BES-CFD simulations. Also the works on time-resolved modelling of street canyons will continue. Additional work will focus on the topic of how to extract boundary conditions for the urban micro- and local scale CFD modelling. Results of this work are also transferred to the CCEM project Archinsolar for the analysis of heat transfer in building integrated photovoltaic panels.

Experimental evaluation: Street canyon experiments in the wind tunnel will be continued for different wall/ground surface temperature and upstream configurations. Comparisons are also planned with results gained by PIV experiments done at other institutions. The test set-up will also be used for the experimental modelling of solar radiation-flow interactions in urban configurations (post-doc work of Parham Mirzaei [13]).

Energy impact assessment: The methodology developed for the energy impact assessment will be applied to typical urban cases, and, based on the knowledge gained from the simulations, conclusions on urban building energy design will be drawn.

Publications: In 2012, again a number of scientific conference (e.g. for Int. Building Physics Conf. and 8th Int. Conf. on Urban Climate) and scientific journal publications are planned. Most important, the results of this project will be documented in the PhD thesis of Jonas Allegrini.

Referenzen

[1] Rotach M. et al. 2005. ***BUBBLE – an urban boundary layer meteorology** p**roject***. Theor. Appl. Climatol. 81, 231–261

[2] Stettler S., Dorer V**.** 2011. ***Analysis of UHI effect on heating and cooling demand.*** *Subproject to "Urban Climate and EnergyDemand in Buildings",* Basler & Hofmann AG, Zürich, 31.03.2011.

[3] Defraeye T., Blocken B., Carmeliet J. 2011. ***An adjusted temperature wall function for turbulent forced convective heat transfer for bluff bodies in the atmospheric boundary layer.*** Building and Environment 32: 2130-2141

[4] Liu Y., Harris D. 2007. ***Full-scale measurements of convective coefficient on external surface of a low-rise building in sheltered conditions***. Build Environ 2007, 42(7):2718-36.

[5] Allegrini J., Dorer V., Defraeye T., Carmeliet J. 2012. ***An adaptive temperature wall function for mixed convective flows at exterior surfaces of buildings in street canyons***. Building and Environment. 49: 55-66

[6] Moonen P., Dorer V., Carmeliet J. 2011. ***Evaluation of the ventilation potential of courtyards and urban street canyons using RANS and LES***. Journal of Wind Engineering & Industrial Aerodynamics 99: 414–423

[7] Moonen P., Gromke Ch., Dorer V., Carmeliet J. 2011. ***LES of dispersion in a street canyon with tree planting***. PHYSMOD2011 – International Workshop on Physical Modelling of Flow and Dispersion Phenomena, Hamburg, Aug. 22-24, 2011

[8] Moonen P., Dorer V., Carmeliet J. 2011. ***On the relevance of incorporating flow unsteadiness in simulations of wind flow in the urban environment.*** ICWE13, Amsterdam, The Netherlands, July 10-15, 2011.

[9] Allegrini J., Dorer V., Carmeliet J. 2011. ***Influence on the urban microclimate on the energy demand of buildings***. Cisbat11, Lausanne Sep 14-16 2011

[10] Allegrini J., Dorer V., Carmeliet J. 2011. ***Analysis of convective heat transfer at building façades in cities and its influence on the energy demand in buildings***. ICWE13, Amsterdam, The Netherlands, July 10-15, 2011.

[11] Allegrini J., Dorer V., Carmeliet J. 2011. ***Buoyant flow in a street canyon: comparison of CFD simulations and wind tunnel measurements***. PHYSMOD2011 – International Workshop on Physical Modelling of Flow and Dispersion Phenomena, Hamburg, Aug. 22-24, 2011

[12] Carmeliet J. 2011. ***Towards energy positive, comfortable and healthy cities. A multiscale approach***. Smart Energy Strategies Conference 2011, Zürich, Sep. 21 – 23, 2011

[13] Mirzaei P.A., Haghighat F. 2010. ***Approaches to study urban heat island – abilities and limitations.*** Building and Environment 45 (10), 2192-2201