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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 will be performed using computational fluid dynamics (CFD) techniques. Validation experiments in selected isothermal and non-isothermal cases will be undertaken (air flow patterns, temperature distributions) in the new atmospheric boundary layer wind tunnel at Empa. 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 shall be investigated.

In the present phase of the project, an urban quarter typology was established for major Swiss cities and detailed for the city of Basel. For these quarters, different urban heat island intensity effects on heating and cooling demand were analysed. To model flow and heat transfer phenomena in the urban canopy, the coupling of CFD and whole-building simulation models was established. In addition the influence of time resolved modelling on the ventilation of street canyons was analysed. Concepts for the envisaged experimental evaluations in the atmospheric boundary layer wind tunnel at Empa have been discussed, considering the scaling laws and the respective limitations in wind tunnel testing. First tests with the new particle image velocimetry system were performed.

In the year 2011 coupled simulations will be performed for typical street canyon situations. However, methods to reduce the computational demand for the CFD simulations are crucial for coupled simulations. Issues like customized wall function modelling will be further developed. Time-resolved street canyon experiments will be performed in the wind tunnel, and compared with results from CFD simulations and also water tunnel measurements (performed at University of Cyprus). For the energy impact assessment, the methodology will be further detailed and first results produced.

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 (Fig. 1).

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 CFD with building energy simulation 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.

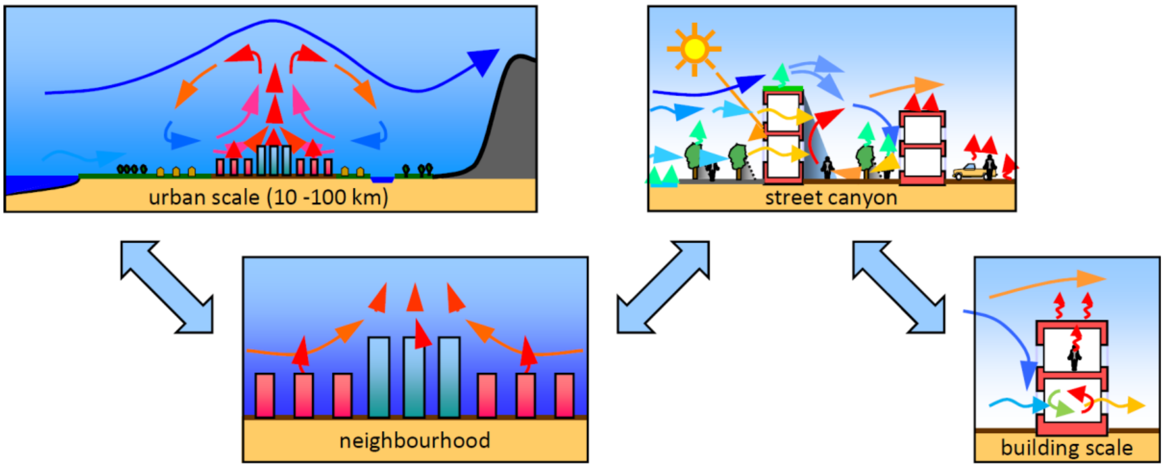

Fig. 1: The multi-scale aspects of urban climate modelling.

The following project milestones are set:

(i) Definition of typical quarter morphologies of Swiss cities

(ii) Analysis of urban heat island (UHI) effects on heating and cooling demand

(iii) Heat transfer modelling and CFD simulation: microclimate in street canyons and urban areas

(iv) Wind tunnel experiments: selective empirical validation

(v) Impact assessment: urban climate and building energy demand

The results of the project are a methodology and the respective models to assess the impact of urban morphology and physical properties on the urban microclimate. Additionally, a more profound insight in the mechanisms and the impacts of the urban climate on the energy demand in buildings shall be given. Key topics in this respect are: decreasing heating demand, increasing cooling demand, daytime natural ventilation, passive cooling by night-time ventilation.

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: A comparison of urban quarters of Basel with surrounding rural quarters showed between 10% and 30% less heating degree days in the city than in the rural locations. The urban quarters themselves showed also significant differences in the UHI effect. To determine the reason for these differences, an evaluation of factors causing different UHI intensities was made based on literature (e.g. [2]). It revealed that depending on the weather and daytime situation different factors are relevant for the UHI effect. Furthermore, the same factor (e.g. vegetation) can lead to an increase or a decrease of the UHI effect, depending on the weather and the daytime. For the urban quarters of Basel, correlations for a multitude of different parameters were investigated, and the effects on heating and cooling demand quantified. A draft report is established [3] and the final report will be available by March 2011.

Modelling: The coupling of CFD (*Fluent*) and whole-building simulation (*TRNSYS*) models is established. However, methods to reduce computational demand for the CFD simulations are crucial for coupled simulations [4], [5]. Therefore, recent work focused on 2D street canyon flow models. For these cases the effects of different modelling approaches of the near wall region and thus on the convective heat transfer coefficients were investigated (low-Reynolds number modelling, standard wall functions, customized wall functions [6]). 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. The results clearly indicated the importance of unsteadiness on the exchange fluxes, as predicted by LES [7].

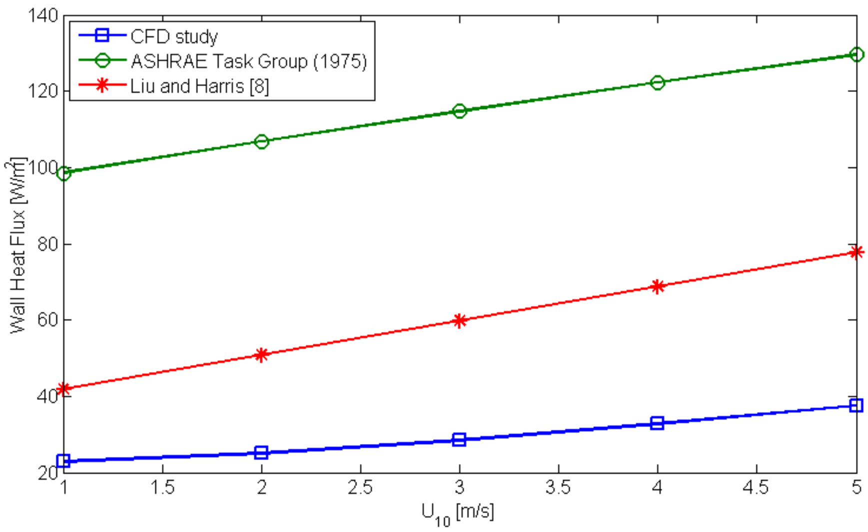

Fig. 2: Comparison of convective wall heat flux in function of wind speed

Experimental evaluation: The installation of the new atmospheric boundary layer wind tunnel at Empa is completed. Due to several problems in regard to the commissioning and the set-up of the particle image velocimetry (PIV) system, no project specific street canyon measurements could be made yet. Problems included laser and beam optics adjustments, laser light sheet intensity and overlap, and the problem of laser light reflections from the street canyon models, leading to impermissible high light intensities in the high-resolution, high-speed cameras.

Publications: The project was presented at the brenet Status Seminar [9]. The paper submitted by Moonen et al. [7] is accepted for publication.

Nationale Zusammenarbeit

Inherently, a close collaboration is established with the Chair of Building Physics at ETHZ. Links exist also to research institutions working in the fields of energy as well as urban planning, urban morphology and building typology (e.g. EPFL-LESO, HSLU T&A CCTP). Contacts with researcher and institutions working in meso- and large- scale weather and climate prediction modelling were intensified, namely with the Centre for Climate Systems Modelling (C2SM) and with Prof. M. Rotach (Uni Innsbruck since 06/2010, formerly at ETHZ and MeteoSwiss).

Internationale Zusammenarbeit

Collaboration with University of Cyprus (UCY) (Prof. Marina Neophytou) was established in regard to experimental and CFD validation. UCY runs a similar PIV system as used at Empa, but in a water tunnel. Parallel and supplementary tests in respect to mixed convection in street canyons are planned for 2011 both at Empa and UCY. 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.

Bewertung 2010 und Ausblick 2011

Case study situations: Basler & Hofmann AG as the project partner focussing on city morphologies and evaluation of UHI effects will extend its project involvement until March 2011. A focus will be set on determining the most important architectural factors that influence the UHI effect. A separate report on the analysis of UHI effect on heating and cooling demand will be issued by March 2011.

Modelling: Methods for the coupling of CFD (*Fluent*) and whole-building simulation (*TRNSYS*) will be further developed. The analysis of different modelling approaches of the near wall region will be documented. The different heat transfer coefficient correlations will be derived as function of the wind speed and then used in the whole-building simulation to predict the cooling demand of stand-alone buildings and buildings in a street canyon for typical time periods in the city of Basel. In future work, CFD simulations will be conducted for each time step of the whole-building simulation for the determination of the heat transfer coefficients. 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 from data gained with fine-grid meso-scale weather and climate prediction models, such as the *COSMO-2* model.

Experimental evaluation: Street canyon experiments will start as soon as the set-up of the PIV system in the new atmospheric boundary layer wind tunnel for these measurements is established. Comparisons are also planned with results gained by water channel PIV experiments and CFD simulations at the University of Cyprus.

Energy impact assessment: The methodology for the energy impact assessment will be further detailed in early 2011, based on the knowledge gained from the modelling, and first simulation results will be produced.

Publications: As mentioned, the analysis of UHI effects will be issued as separate project report. Two papers are proposed for the 2011 International Conference on Wind Engineering. Additional papers on the heat transfer modelling and on the effects of turbulence in street canyons are in preparation.

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