INFLUENCE OF MICROMETEOROLOGICAL CONDITIONS IN A STREET CANYON ON ENERGY CHARACTERISTIC OF A BUILDING

Marcin
Idczak

Summary

The micrometeorological conditions in a street canyon may vary significantly from reference weather conditions. In result the energy consumption of a building for heating and cooling purposes can be affected. A methodology for evaluation of the influence of micrometeorological conditions in a street canyon on building energy characteristic using coupled CFD and thermo-radiative modelling is presented. A preliminary study results indicate that considering only thermo-radiative effects (no airflow around building studied), a street canyon configuration enhances energy savings for air-conditioning with 27% lower energy demand in relation to reference case (detached building) during a hot clear-sky summer day.

Keywords: Street canyon, micro-meteorological conditions, energy demand of a building

1 Introduction

This paper presents a methodology adopted in a co-tutelage PhD project bringing together the experiences of Laboratoire de Mecanique des Fluides, ECN (urban micrometeorology) and Institute of Heating and Ventilation, WUT (energy and buildings). The project aims to evaluate the influence of micrometeorological conditions in a street canyon on energy characteristics of a building.

Street canyon is a basic and typical element of an urban structure. The mutual interactions between the buildings and atmosphere and the heat transfer processes taking place within the canyon result in establishing specific micrometeorological conditions. The thermo-radiative balance is modified and sheltering effects occur which in general leads to air temperature rising. With a series of uniform street canyons forming a quarter and a number of quarters forming a city, a large-scale effect of urban heat island emerges.

The micrometeorological conditions in a street canyon may vary significantly from reference weather conditions. In result the energy consumption of a building for heating and cooling purposes can be affected.

Following micrometeorological factors may influence an energy balance of a building:

- as the building is sheltered from wind, the sensible heat transfer on the external envelope of a building will be reduced since the sensible heat transfer coefficient value is correlated with wind speed,
- wind sheltering will also reduce air infiltration into the building and related heat exchange,
- a building in a street canyon is shadowed by adjacent buildings which results in lower heat gain from direct solar radiation,
- multi-reflections of solar radiation trapped within a street canyon result in higher heat gain from diffuse solar radiation,
- as the long-wave radiative balance of the building is always negative, the infrared heat loss will be lower since the building is screened from the horizon with walls of adjacent buildings.

The objective of this PhD project is to try to quantify these effects by comparing energy demand of a building situated in a street canyon with a reference case of an identical detached building. The micrometeorological conditions around the buildings will be generated with coupled CFD and thermo-radiative modelling using reference weather data as input. The results will be used to calculate the energy demand of a building for heating and cooling purposes.

2 Methodology

2.1 Models

Two numerical models are used to generate micrometeorological conditions around buildings: CHENSI CFD model and SOLENE thermo-radiative model.

CHENSI is a full Reynolds-averaged Navier-Stokes Computational Fluid Dynamics code (Sini et al., 1996), developed at Laboratoire de Mecanique ds Fluides at Ecole Centrale de Nantes. The model is used to analyse in-street wind flows and traffic pollutant dispersion at local scales. SOLENE has been developed at Cerma Laboratory at Ecole d’Architecture de Nantes in order to study the environmental aspects of urban structures (Miguet et al., 1996). Based on the 3D model of finite elements it allows evaluation of direct and diffuse solar radiation components and determination of solar energy absorbed, taking into account multiple reflections between the buildings and the ground. SOLENE enables estimation of the resulting surface temperatures as well as the infrared radiative fluxes.

Both models have been validated. The results of experimental campaign JAPEX (Idczak et al., 2006) were used to corelate the experimantal site simulation results with the measurements giving a good agreement.

Two models are coupled to obtain complex micrometeorological data. First run is done with SOLENE, with reference weather data as input. Resulting surface temperatures are used together with weather data to run CHENSI. Resulting sensible heat transfer coefficients are the modified input to secondary run with SOLENE. Finally a set of complex micrometeorological data around building is obtained for energy calculations.

2.2 Examined buildings and configurations

A typical cuboidal building is analysed. Since the models have already been validated for certain geometry, the building is similar to building models examined in JAPEX campaign.

The building is long (L>>H), constructed of three identical segments. The building dimensions are as follows: building width is B = 10 m, building height is H = 20 m, segment length is L = 40 m. Half of each façade surface is glazed. In order to eliminate the impact of end-effects only the central segment is analysed. The building is surrounded along with identical rows of buildings from both sides. The street width is W = 8 m. The aspect ratio of a street canyon (W/H) is 0.4 (like during JAPEX campaign). This value is very typical for European cities. In the reference case the building is isolated with no surrounding buildings.

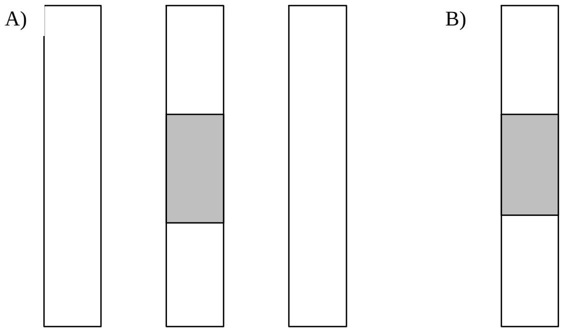

Fig. 1 Examined configurations: A) building in a street canyon, B) detached building

1.1 Reference weather data

The simulations are carried out for the reference weather data for Warsaw. Three days are analysed: i) a hot clear-sky day in summer, ii) a cold day in winter with very low temperature and clear sky, iii) a cold day in winter with low temperature and cloudy sky. Only three basic cases are analysed to reduce computing effort, giving at the same time satisfactory overview on the problem throughout the season (heating and cooling demand).

1.2 Energy calculations

The energy balance of a building is composed of three elements:
- heat transfer through windows,
- heat transfer through non-glazed building envelope,
- heat transfer related with building ventilation.

Simulation results provide all necessary data needed to carry out the energy calculations: radiative heat transfers received, emitted, reflected or transmitted by each building surface (solar and IR radiation), sensible and subsurface heat transfers, pressure and temperature fields around the building. The temperature inside the building is assumed to be constant (the heat fluxes are balanced with heating or cooling systems). With flow paths through building envelope assumed the ventilation rate and heat exchange related with building ventilation can be found.

3 Preliminary results

1.3 Introduction

For the purpose of this paper a simple, preliminary study was prepared. A thermo-radiative balance comparison of a building situated in a street canyon with a reference case (a detached building) was carried out with SOLENE. The buildings were situated along N-S axis. The computations were carried out for a hot clear-sky summer day (9 July, Meteonorm weather data) for a period of 24 hours with 1 hour timestep.

The airflow around buildings was not analysed in this study. Air infiltration and building ventilation were not treated neither. The wind speed and resulting sensible heat transfer coefficient value were assumed to be constant throughout the day ($h_c = 10$ W/m^{2}K). Physical properties of domain materials used for calculations are presented in the table below.

Tab. 1 Physical properties of domain materials

	d [m] Thickness	**a [-]** Surface albedo	**ε [-]** Emissivity	**λ [W/mK]** Thermal conductivity	**c_p [J/kgK]** Specific heat	**ρ [kg/m^3]** Volumic mass
Building envelope						
Concrete	0.2	0.5	0.9	0.93	653	2300
Ground						
Concrete	0.2	0.5	0.9	0.93	653	2300
Soil	1.8	-	-	1.00	1500	1440

1.4 Discussion

Following results present average energy fluxes per square metre for two building walls (S – southern façade, N – northern façade) and building roof (H).

Fig. 2 presents the comparison of solar radiation incident on building envelope. The results show that solar radiation incident on facades of a building situated in a street canyon (A) is much lower than in reference case (B). This flux will affect the heat gains through non-glazed building envelope, but mostly the heat gains through windows. Considering that 50 % of solar radiation incident on window surface is transmitted into the building through the glass, the diurnal heat gains through windows will reach 3586 Wh/m^2 for a building in a street canyon and as much as 5457 Wh/m^2 for a detached building.

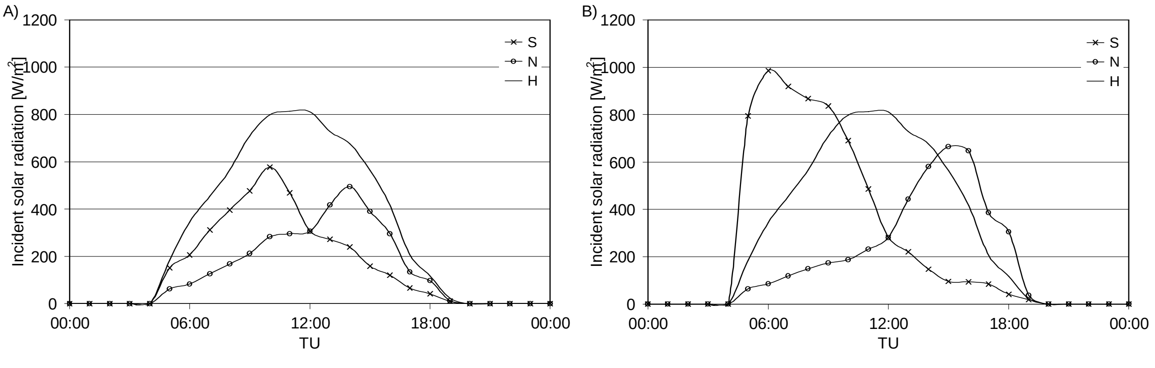

Fig. 2 Incident solar radiation: A) building in a street canyon, B) detached building

Fig. 3 presents net thermal radiation balance of a building envelope which is always negative. Adjacent buildings cover the horizon and heat loss at building walls is little lower in case of a building in a street canyon (A). The highest loss takes place at building roof and has certainly the same value for both examined cases.

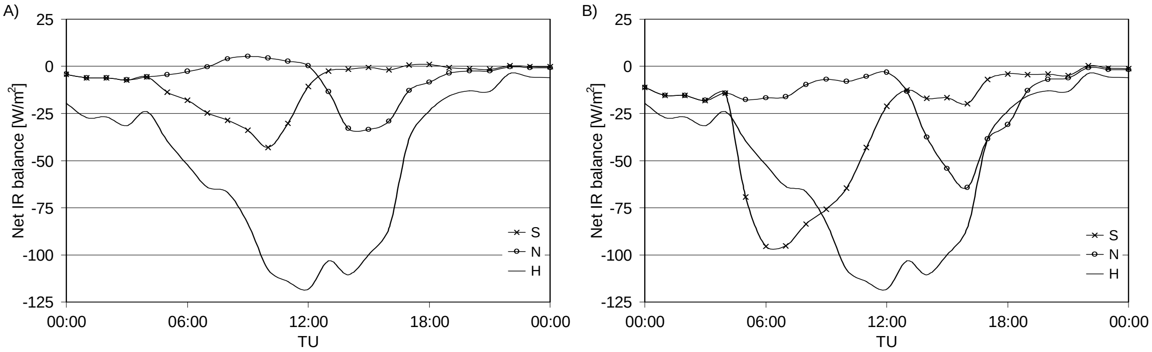

Fig. 3 Net IR balance: A) building in a street canyon, B) detached building

The last two graphs (**Fig. 4**) present the net energy balance of a non-glazed building envelope. The heat is lost during night and the building cools down. During the day the heat is conducted through the envelope into the building and stored or taken away by air-conditioning system. Diurnal heat gains through building walls reach 1176 Wh/m^2 in case of a building in a street canyon (A) and 1469 Wh/m^2 in a reference case (B).

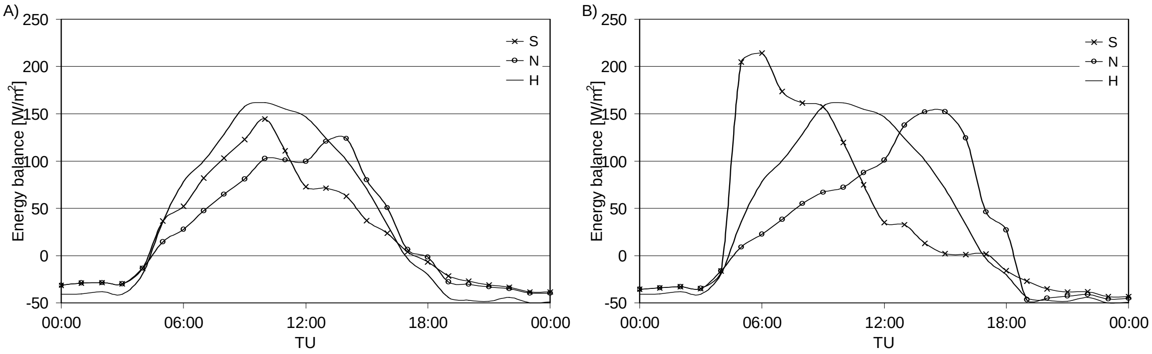

Fig. 4 Energy balance of building envelope: A) building in a street canyon, B) detached building

Overall diurnal energy balance of a building reaches 4.61 kWh for a building in a street canyon and 6.34 kWh for a reference case (heat exchange with the ground and adjacent buildings neglected). This means that during a hot clear-sky day, a building in a street canyon will consume 27 % less energy to take away the heat gains through building envelope and solar heat gains through windows with air-conditioning system.

4 Conclusions

- Street canyon configuration enhances energy savings for air-conditioning in summer with lower energy demand.
- Notice that the differences in energy balance between a building situated in a street canyon and detached building (reference case) result mostly from different solar heat gains through windows value.
- The work will follow with complete energy analysis considering building ventilation and sheltering effects. The impact of street canyon micrometeorological conditions on energy characteristics of a building in winter needs to be examined.
- Proposed methodology gives good prospects for energy balance analysis of various urban projects.

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Marcin Idczak
✉ Institute of Heating and Ventilation
ul. Nowowiejska 20
00-653 Warsaw, Poland
☎ +48 22 234 78 87
🗐 +48 22 825 29 92
☺ midczak@nape.pl
URL www.iow.is.pw.edu.pl