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Računalniška analiza ogrevalnih in hladilnih obremenitev za različne tipe stavb

A Computer Analysis of Heating and Cooling Loads for Different Types of Building

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Prispevek prikazuje simulacije ogrevalnih in hladilnih obremenitev za različne tipe stavb s programskim paketom TRNSYS. Prikazujemo sedem različnih tipov stavb in štiri različne klimatske pogoje v Evropski zvezi. Skupaj je narejenih 28 simulacij, v tem prispevku pa prikazujemo rezultate za pisarniško zgradbo.
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(Ključne besede: zgradbe pisarniške, energija toplotna, simuliranje obremenitev, analize računalniške)

This paper presents simulations of heating and cooling loads for different types of building with the TRNSYS programme package. We present seven different building types and four different weather conditions in the European Union. Altogether we made 28 simulations and the results for an office building are shown in this paper.
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(Keywords: office buildings, thermal energy, load simulation, computer analysis)

0 UVOD

Toplotne in hladilne obremenitve so toplotna energija, ki jo moramo dovesti ali odvesti iz notranjosti prostora stavbe, da ohranimo karakteristike ugodja. Ko obremenitve določimo, se je treba lotiti določevanja opreme za ogrevanje in hlajenje.

Najpomembnejša skrb inženirjev je določiti največjo obremenitev, ker je od te odvisna moč opreme. Le-ta se ujema z ekstremnimi vrednostmi vročega ali hladnega vremena, ki jih imenujemo *projektni pogoji*. Naftna kriza je izostrila našo zavest do energije in računalniška revolucija je dala opremo za optimiranje projektiranja stavb in za izračun stroškov energije.

Svež zrak v stavbi je pomemben za ugodje in zdravje. Energija za pripravo tega zraka je pomemben dejavnik. Premalo zraka povzroča sindrom bolne stavbe, preveč zraka pa povzroča večjo rabo energije. Izmenjava zraka je mišljena kot tok zunanjega zraka, ki prečka mejo poslopja in ga je treba klimatizirati. Pogosto je primerno, da ga delimo s prostornino stavbe, kar izražamo v enotah izmenjav zraka na uro.

1 TRNSYS

Za simuliranje smo uporabili računalniški program TRNSYS [1] (‘tran-sys’), ki je komercialno

0 INTRODUCTION

Heating and cooling loads are thermal energy that must be supplied or removed from the interior of a building in order to maintain comfortable conditions. Once the loads have been established, one can proceed to the supply side and determine the performance of the required heating and cooling equipment.

Of primary concern to engineers are the peak loads, because they determine the capacity of the equipment. They correspond to the extremes of hot and cold weather, and are called *design conditions*. The oil crises have sharpened our awareness of energy, and the computer revolution has given us the tools to optimise the design of a building and to compute the cost of energy.

Fresh air in a building is essential for comfort and health, and the energy for conditioning this air is an important factor. Not enough air, and one risks sick-building syndrome; too much air, and one wastes energy. The supply of fresh air, or air exchange, is stated as the flow rate of the outdoor air that crosses the building boundary and needs to be conditioned. Often it is convenient to divide it by the building volume, expressing it in units of air changes per hour.

1 TRNSYS

For the simulation we have used the TRNSYS [1] (‘tran-sis’) computer programme, comna voljo od leta 1975 in je namenjen simuliranju prehodnih pojavov toplotnih sistemov. TRNSYS je za reševanje problemov zasnovan modularno in uporablja računalniški jezik Fortran. Na primer podprogram Type 32 vsebuje model hladilne naprave. Podprogram Type 56 vsebuje model večconske zgradbe. Vsak modul ima vhod in izhod. Velikost tokov ter temperature vode in zraka so vstopni podatki za modul Type 32, medtem ko sta celotna in latentna toplotna moč izhodna podatka iz modula. Z izdelavo vhodnega modela uporabnik ukaže TRNSYSu, kako naj poveže module med seboj, ki tako tvorijo sistem. TRNSYS potem kliče posamezne podprograme glede na vhodno datoteko in iterira podatke v vsakem časovnem koraku, dokler sistem enačb ni rešen. Alternativa tej metodi je za raziskovalce, da napišejo enoten program, ki modelira samo en sistem. Toda vsakršne spremembe so pri takem programu bolj zapletene, kakor če uporabljamo TRNSYS.

2 REFERENČNE STAVBE

Pri naših simuliranjih smo uporabili naslednje objekte [4]:

- pisarno
- bolnišnico
- hotel
- šolo
- prodajalno
- stanovanjsko poslopje
- enodružinsko stavbo

Za **pisarniški objekt smo** uporabili World Trade Center v Ljubljani. Zgradba je usmerjena na sever-jug. Tloris ima izmere 28,35 x 25,6 m. Ima pritličje (4,5 m višine) + eno nadstropje (4,5m) + 15 nadstropij z višino 3,5m. Streha ima strmino 12°. Celotna višina objekta na jugu je 61,5m.

Za **bolnišnico** smo vzeli porodnišnico Univerzitetnega kliničnega centra v Ljubljani. Tloris poslopja je 44 x 38 m. Usmerjena je na sever-jug. Višina poslopja je 24 metrov (pritličje + 5 nadstropij, višina enega nadstropja je 4m). Prostornina poslopja je 44 x 38 x 24 = 40128 m^3.

Hotel ima tloris 18 x 40 m in prostornino 36000 m^3. 100 % je zaseden v poletni in 35% zimski sezoni. Povedali so nam, da je povprečna temperatura v hotelu pozimi 23 °C in poleti 21 °C.

Za **šolo** smo uporabili poslopje s tlorisom 30 x 80 m (okoli 8 razredov v vsakem od dveh nadstropij). Pouk teče (v razredih na levi) samo od 8:00 do 15:00 ure. V njej je 500 učencev in učiteljev. V popoldanskem času so samo dejavnosti v telovadnici (prostor na desni) in je v uporabi do 22:00 ure. Učence jemljemo kot standardne osebe.

mercially available since 1975, which is designed to simulate the transient performance of thermal energy systems. TRNSYS relies on a modular approach to solve large systems of equations described by Fortran subroutines. Each Fortran subroutine contains a model for a system component. For example, Subroutine Type 32 contains a model of a cooling coil. Subroutine Type 56 contains a model of a multizone building. Each component has inputs and outputs. The inlet flow rates and temperatures for the air and water are inputs to the Type-32 model, while the total and latent cooling rates are among the outputs of the model. By creating an input file, the user directs TRNSYS to connect the various subroutines to form a system. The TRNSYS engine calls the system components based on the input file and iterates at each timestep until the system of equations is solved. The alternative to this method is for the researcher to write a single, monolithic program that models only the system at hand. Subsequent changes to the system configuration are more difficult with monolithic programs than they are with modular programs such as TRNSYS.

2 REFERENCE BUILDING

In our simulations we have taken the following reference buildings [4]:

- office
- hospital
- hotel
- school
- store
- apartment house
- single house

For the **office building** we have used the World Trade Centre in Ljubljana. The building has a north-south orientation. The ground plan has dimensions of 28.35 x 25.6 m. It has a ground floor (height 4.5 m) + one floor (4.5m) + 15 levels with a height of 3.5m. The roof has an angle of 12°. The total height of the object to the south is 61.5 m.

For the **hospital** we chose the maternity hospital at University Clinical Centre. The ground plan of the building is 44 x 38 m. It is oriented north-south. The height of the building is 24 meters (ground floor + 5 floors, the height of 1 floor is 4m). The volume of the building is 44 x 38 x 24 = 40128m^3.

The **hotel** has a ground plan of 18 x 40 m and a volume of 36000 m^3. It has 100 % occupancy in the summer and 35 % in the winter. We were told that the temperature of the hotel in winter is 23°C and in summer 21°C.

For the **school** we took a building with a ground plan: 30 m x 80 m (cca. 8 classes on each of two floors). The lessons are only in progress (rooms on the left) from 8:00 till 15:00 hrs. There are 500 pupils and teachers. In the afternoon there are some activities only in the gymnasium (room on the right) which is in use till 22:00. The pupils are taken as standard persons.

Za primer **prodajalne** smo uporabili supermarket MERCATOR. Nova stavba, ki je bila zgrajena leta 1999, ima tloris 170 m x 110 m z višino 8 m. Daljša fasada je usmerjena na JV-SZ. Prostornina poslopja je V = 170 x 110 x 8 = 149600 m^3.

Za **stanovanjsko poslopje** smo uporabili večdružinsko stavbo. Stavba je usmerjena na sever-jug. Tloris meri 16 m x 64 m. Imamo pritličje in 12 nadstropij ter podstrešje. Višina nadstropja je 3 m in stavba je za 270 ljudi. Prostornina je 40960 m^3 (224 stanovanjskih enot). Streha je ravna in pohodna.

Za **enodružinsko hišo** smo analizirali hišo za eno družino v ljubljanskem predelu Murgle. Tloris stavbe je 15 x 8 metrov in je usmerjena na sever – jug.

As an example of the **store** we took a MERCATOR supermarket. A new building which was built in 1999 and has a ground plan of 170 m x 110 m with a heiht of 8 m. The long facade is oriented towards SE-NW. The volume of the building is 170 x 110 x 8 = 149600 m^3.

For the **apartment house** we took a multi-family building. The building is oriented north-south, the ground plan is 16 m x 64 m. There is a ground floor plus 12 flats, plus attics. The height of each flat is 3m and the building is for 720 people. The volume is 40960 m^3 (224 living units). The roof is flat and walking.

For the **single house** we have analysed a house for one family in the Murgle area of Ljubljana. The ground plan of the house is 15 x 8 meters and is oriented north-south.

3 KLIMATSKI PODATKI

Tipe stavb, predstavljene v 2. poglavju smo simulirali s štirimi klimatskimi pogoji v Evropi. Uporabili smo Testno referenčno leto (TRL - TRY) [2] za naslednje države:

- Velika Britanija – London
- Švedska – Stockholm
- Italija – Rim
- Slovenija – Ljubljana

Podatki za TRL so sestavljeni iz mesečnih vrednosti različnih let. Za Ljubljano je Testno referenčno leto sestavljeno iz podatkov v letih 1961 do 1980. Testno referenčno leto vsebuje naslednje podatke:

1) Številko dneva v letu (1 do 365),
2) Zunanjo temperaturo (°C)
3) Relativno vlažnost (%)
4) Hitrost vetra (m/s)
5) Globalno sevanje na vodoravno ploskev (kJ/hm^2) – če je vrednost nič, potem je podano neposredno sončno sevanje
6) Uro v dnevu
7) Neposredno sončno sevanje (kJ/hm^2) – če je vrednost nič, potem je dano globalno sevanje
8) Difuzno sončno sevanje (kJ/hm^2) - če je vrednost nič, potem je dano globalno sevanje

3 CLIMATE DATA

The building types described in section 2 have been simulated in four different climatic conditions for Europe. We have used a Test Reference Year (TRY) [2] for the following countries:

– United Kingdom – London,
– Sweden – Stockholm,
– Italy – Rome,
– Slovenia – Ljubljana.

Data for the TRY are made up from months of different years. For the Ljubljana Test Reference Year was taken data from years 1961 to 1980. Test Reference Year is a file of data which contains:

1) Number of days in the year (1 to 365),
2) External temperature (°C),
3) Relative humidity (%),
4) Wind velocity (m/s),
5) Total horizontal radiation (kJ/hm^2) – if the value is zero then data for direct radiation is given,
6) Hour in the day,
7) Direct solar radiation (kJ/hm^2) – if the value is zero then only the total solar radiation is given,
8) Difuse solar radiation (kJ/hm^2) - if the value is zero then only the total solar radiation is given.

4 SIMULIRANJA

Simuliranja smo izvajali s programom TRNSYS s podatki za objekte (poglavje 2) in s podatki za testno referenčno leto (poglavje 3).

Za vse primere smo vzeli nespremenljiv koeficient toplotne konvekcije znotraj in zunaj zidu. Po DIN 4701 – del 2 ([3] in [5]) smo uporabili:

- za zunanji prenos toplote 22,7 W/m^2K (81,7 kJ/hm^2K),
- za notranji prenos toplote 7,7 W/m^2K (27,7 kJ/hm^2K),
- za notranji prenos toplote – strop 5,88 W/m^2K (21,2 kJ/hm^2K).

4 SIMULATIONS

Simulations have been made using TRNSYS with building data (section 2) and with a Test Reference Year (section 3).

For all cases we took the constant convective heat-transfer coefficient inside and outside the wall. By DIN 4701 – Part 2 ([3] and [5]) we have used:

- for external heat transfer 22.7 W/m^2K (81.7 kJ/hm^2K),
- for internal heat transfer 7.7 W/m^2K (27.7 kJ/hm^2K),
- for internal heat transfer 5.88 W/m^2K (21.2 kJ/hm^2K).

Za vse primere je absorptivnost stene 0,6 (sončna absorptivnost stene). V primerih, ko imamo pred zidom steklo je celotna absorptivnost 0,6. Transmitivnost stekla reflectafloat je 57%, tako je absorptivnost stene 0,6 x 0,57 = 0,34. Reflektivnost okolice je 0,2.

Za vse primere smo uporabili bruto prostornino. V tem primeru je prostornina od 20 do 30% večja od prostornine zraka v stavbah. V vseh primerih smo vzeli infiltracijo 0,6 izmenjav zraka na uro. V vseh primerih je bilo vključeno ogrevanje/hlajenje z razvlaževanjem 50%.

Vsi primeri so bili narejeni tako, da je celoten zrak za ventilacijo vstopa v stavbo z zunanjo temperaturo (brez rekuperacije toplote). Zaradi tega so individualni toplotni tokovi prikazani posebej.

Za geografsko širino smo vzeli:
Ljubljana 46,22 S,
London 51,15 S,
Stockholm 59,35 S,
Rim 41,80 S.

Vsa simuliranja so bila narejena za vse leto. V datoteki z rezultati imamo naslednje podatke:

1. TIME	ura v letu (1 do 8760)
2. NO. OF DAY	številka dneva v letu (1 do 365)
3. DATE	datum dneva v letu (1.1. do 31.12)
4. Hour	ura v dnevu (0 do 24)
5. Toutside	zunanja temperatura (°C)
6. Tinside	notranja temperatura v stavbi. (°C) – temperatura v coni
7. Qsensible	senzibilni toplota (- ogrevanje, +hlajenje) (kJ/h)
8. Qsur	konvekcija zraka iz vseh sten v coni (kJ/h)
9. Qinf	infiltracijski energetski dobitki (kJ/h)
10. Qv	ventilacijski energetski dobitki (kJ/h)
11. Qg_c	notranji konvekcijski dobitki (kJ/h)
12. Qg_l	latentni energetski dobitki (kJ/h)
13. Qg_r	celotni notranji sevalni dobitki (kJ/h)
14. QUA_trans	stacionarne izgube sten in oken v coni z uporabo »k« vrednosti, podane v izračunu (kJ/h)

Prezračevalne izgube so izračunane pri svežem zraku z zunanjo temperaturo. Tako so te izgube/dobitki zelo pomembni in se izračunajo po enačbi:

For all cases the absorbtivity of the walls was 0.6 (Solar Absorbtance of wall). In the cases where we have glass in front of the wall the total absorbtivity is 0.6. The transmitivity of the glass reflectafloat is 57 % so the absorbtivity of the wall is 0.6 x 0.57 = 0.34. The reflectivity of the surroundings was 0.2.

For all cases we have used the gross volume. In this case the volume is from 20 to 30 % bigger than the volume of the air in the building. In all cases we have used an infiltration of 0.6 volume air-changes per hour. In all cases heating/cooling was on with dehumidisation at 50% humidity.

All cases were made so that all the air for ventilation comes into the building with the external temperature (without recuperation of heat). For this reason, individual heat fluxes are presented separately.

For the locations the following latitude was used:
Ljubljana 46.22 N,
London 51.15 N,
Stockholm 59.35 N,
Rome 41.80 N.

All simulations have been made for a whole year. In the results file we have the following data:

1. TIME	hour in the year (1 to 8760)
2. NO. OF DAY	number of day in the year (1 to 365)
3. DATE	date for the day in the year (January the 1st to December the 31st)
4. Hour	hour in the day (0 to 24)
5.Toutside	external temperature (°C)
6. Tinside	internal temperature in the building (°C) - air temperature of zone
7. Qsensibile	sensible energy demand (- heating, + cooling) (kJ/hr)
8. Qsur	total convection to air from all surfaces within zone (kJ/hr)
9. Qinf	infiltration energy gain (kJ/hr)
10. Qv	ventilation energy gain (kJ/hr)
11. Qg_c	internal convective gains (kJ/hr)
12. Qg_l	net latent energy gains (kJ/hr)
13. Qg_r	total internal radiative gain (kJ/hr)
14. QUA_trans	stationary U·A-transmission losses of walls and windows of zone using the u-values given in the transfer calculation section (kJ/hr)

Ventilation losses are calculated for necessary fresh air with external temperature. So these losses/gains are very important and they are calculated using the equation:

$$Q_v = \dot{V}.\rho.c_p(T_{vent} - T_{air})$$

kjer je: / where:

$$T_{\text{vent}} = T_{\text{outside}}$$

Ker so rezultati prikazani za vsak mesec posebej, lahko spremenimo prezračevalne rezultate zelo preprosto. Na enak način je izračunana tudi infiltracija, kjer smo uporabili 0,6 izmenjav zraka na uro.

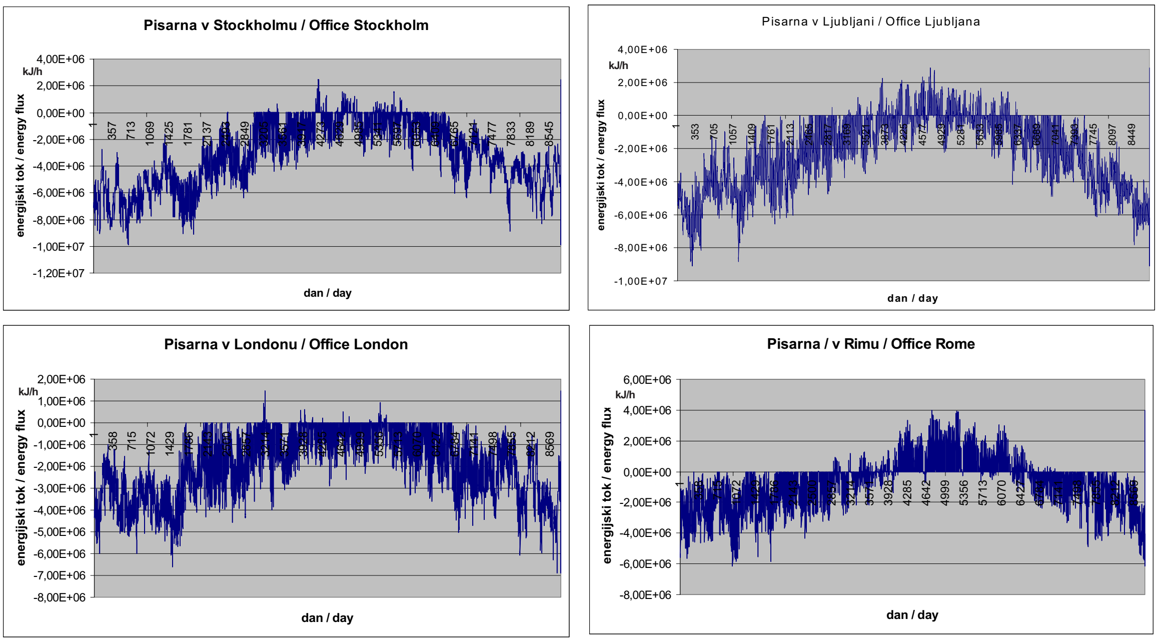
Since the results are shown separately for each hour we can change the ventilation results very easily. In the same way, infiltration is also calculated where we have used 0.6 of volume air-changes per hour.

5 REZULTATI

Skupaj smo naredili 4 x 7 = 28 simuliranj za 8760 ur. Na naslednji sliki predstavljamo rezultate za pisarniško poslopje. Pozitivne vrednosti pomenijo hlajenje, negativne pa ogrevanje.

5 RESULTS

Altogether we have made 4 x 7 = 28 simulations for 8760 hours. In the next figure we present the results for the office building . Positive values mean cooling and negative values mean heating.



Sl. 1. *Primer senzibilnih obremenitev v času enega leta*
Fig. 1. *An example of sensible heat loads for a period of one year*

Za inženirsko uporabo so najpomembnejše najmanjše in največje vrednosti. Na sliki 2 predstavljamo te rezultate za pisarniško poslopje.

For engineering use the most important data are the minimum and maximum values. In Fig. 2 we present those values for the office building.

6 SKLEP

Ugotovili smo, da imata Stockholm in Ljubljana zelo podobne toplotne obremenitve, podobno kakor London in Rim. Razmerje obremenitev med Ljubljano in Rimom pa je 3:2. Na drugi strani so hladilne obremenitve podobne za Ljubljano in Stockholm, medtem ko za London in Rim ugotavljamo razlike, kar je posledica različnih klimatskih razmer.

6 CONCLUSION

We found that Stockholm and Ljubljana have very similar heating loads as do London and Rome. But the ratio between loads in Ljubljana and Rome is 3:2. On the other hand, cooling loads are similar for Ljubljana and Stockholm whereas for London and Rome we found a difference which is the consequence of different climatic conditions.

7 LITERATURA
7 REFERENCES

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[2] Test Reference Year for Ljubljana, London, Stockholm and Rome.
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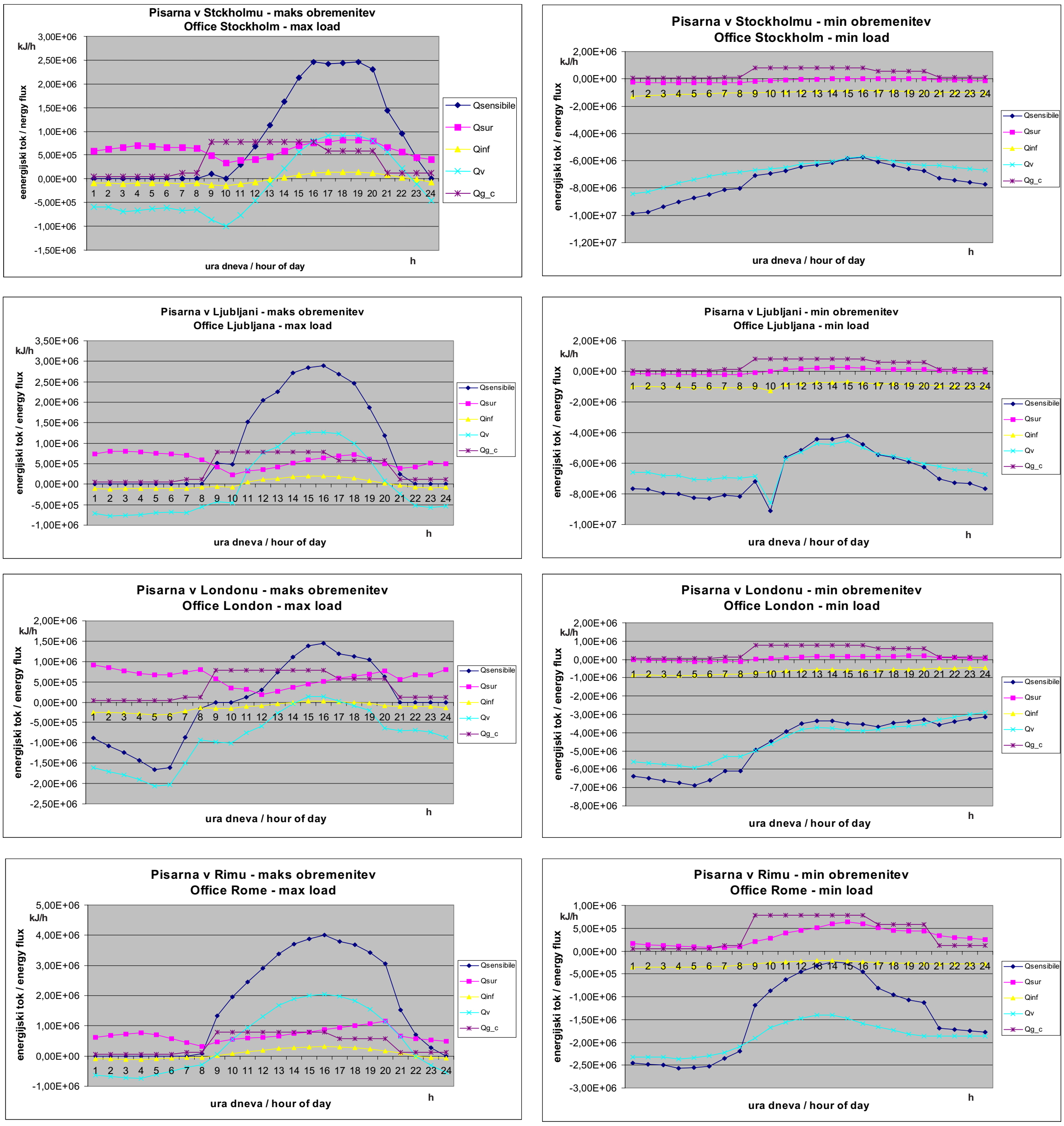

Sl. 2. *Največje in najmanjše obremenitve za pisarniško zgradbo*
Fig. 2. *Maximum and minimum loads for office building*

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