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Okoljski nadzorni sistem - Model vrednotenja zakritih zavetij

An Environmental Control System - Assessment Model for Camouflaged Shelters

J. Howard Arthur - J. Taylor Beard - Robert J. Ribando - Ashok Patil - Nicholas P. Johnston

Kot osnova modela za okoljsko vrednotenje prenosnih zavetij je bil razvit matematični algoritem. Model vrednotenja lahko uporabimo za načrtovanje ogrevalne in hladilne opreme ter za oceno prehodnih toplotnih odzivov zavetij v časovno neustaljenih razmerah okolice. Model se razlikuje od klasičnih modelov KGH (klimatizacija, gretje in hlajenje) v prehodnih odzivih, ki jih lahko vključimo v analizo zavetja. Za javno in poslovno uporabo so trenutno dostopni modeli, s katerimi določimo spremembe prehodnih obremenitev in rabo energije na podlagi določene računske notranje temperature. Z računalniškimi programi, kakršen je npr. TRNSYS, lahko določimo prehodne pogoje v notranjosti, vendar zato potrebujemo natančne vstopne podatke, ki za značilna zavetja običajno niso na voljo. Z novim modelom okoljskega vrednotenja zavetij lahko določimo notranjo temperaturo v odvisnosti od razmer v okolici, delovanja sistemov KGH in notranjih virov.

V algoritmih je za stene zavetja, opremo in notranji zrak uporabljen večvozliščni model, saj se elementi med seboj razlikujejo po svoji toplotni vsebnosti. V model je vključen zastor, obravnavan kot toplotni ščit, z zanemarljivo zmožnostjo shranjevanja energije. Zato izračunamo temperature sevalne zaščitne mreže za vsak časovni korak iz iterativnih energijskih bilanc pri nespremenljivih razmerah. Neznane temperature za vsakega od elementov z zmožnostjo hranjenja energije izračunamo za vsako točko v času z uporabo koračne funkcije, upoštevajoč temperaturo sevalnega ščita. Model je zasnovan tako, da prilagodi toplotne dobitke opreme in osebja ter delovne značilnosti sistemov KGH vremenskim razmeram za določen kraj ali običajnim zunanjim razmeram.

(Ključne besede: okolje, sistemi nadzorni, algoritmi matematični, zavetja, modeli vrednotenja)

Mathematical algorithms have been developed as the foundation of an environmental assessment model for mobile shelters. The assessment model can be used for sizing the heating and cooling equipment and for evaluating the transient thermal responses of shelters under specified initial heat-up and cool-down conditions. This model differs from standard HVAC load models in the form of the transient responses that can be predicted for the shelter. Currently available commercial and public-domain HVAC models predict transient-load variations and energy usage based upon a fixed inside design temperature. Computer codes such as TRNSYS can predict transient indoor conditions, but require detailed input, which is usually not available for the typical shelter. The new, shelter environmental assessment model has the ability to predict inside temperature as a function of variations in environment condition, HVAC equipment performance, and inside load conditions.

The algorithms use a multi-node lumped-capacity model for the shelter walls, the equipment and the air inside the shelter, since each of these elements has an energy-storage capacity. The model includes provisions for modeling camouflage netting as a thermal radiation shield having a negligible energy-storage capacity. Therefore, radiation-shield temperatures are computed from iterative, steady-state energy balances for each time step. The unknown temperatures for the elements with heat capacity are calculated at each point in time using a "marching" solution combined with the radiation-shield temperatures. The model is designed to accommodate the energy gains from equipment and personnel, and HVAC equipment operational features, with weather data for a specific location or from standard outdoor environmental conditions.

(Keywords: environmental control systems, mathematical algorithms, shelters, assessment models)

0 UVOD

Zavetja in šotore uporabljamo za različna podnebja po vsem svetu, na primer za vojaško uporabo kot vojaške postojanke, bolnišnice, latrine, kuhinje, računalniške centre, spalne prostore in kopalnice. Taka zavetja so zelo različna, od platnenih do sestavljenih stenskih profilov z aluminijastimi ploščami na zunanji in papirnato satasto izolacijo na notranji strani. Simulacijske modele lahko uporabimo za določanje toplotnih in hladilnih moči za različna zavetja in šotore, razvite za različne vremenske razmere. Dobljene rezultate lahko uporabimo pri določanju zmogljivosti opreme za nadzor okolja glede na kraj postavitve.

Učinkovito ogrevanje in hlajenje notranjosti zavetij (vzdrževanje temperature in vlažnosti) je postalo nujno za učinkovito delo osebja in opreme. Na primer, komunikacijska oprema deluje v okolju z omejenim spreminjanjem temperatur in vlažnosti. S tem se izognemo nepravilnemu delovanju ali poškodbam na napravah. Posledice premalo zmogljive nadzorne enote notranjega okolja (NENO) bi bile nezdravo in nestorilno delovno okolje in odpoved delovanja opreme. Predimenzionirana NENO pa bi za svoje delovanje potrebovala prevelik generator in bi pomenila veliko oskrbno breme.

1 PODLAGA

V osemdesetih letih prejšnjega stoletja je podjetje BDM International, Inc. izdelalo model izračuna sestave zavetja (MISZ - SAM) [1] za določanje zmogljivosti okoljske nadzorne opreme za prenosna zavetja vojske ZDA. Odvisnost poveljevanja od elektronske opreme se močno povečuje. Zato so po letu 1980 razvili nove oblike zavetij (velikost, snovi in namen uporabe). Metode za določanje toplotnih in hladilnih moči, ki jih priporoča Ameriško združenje inženirjev s področja gretja, hlajenja in prezračevanja ASHRAE, so se v zadnjih dvajsetih letih močno izboljšale. Nekatera predvidevanja prvotnega modela MISZ so postala vprašljiva in neskladna s sedanjimi priporočili ASHRAE [2].

Novi model vrednotenja okoljskega nadzornega sistema smo razvili za izračun ogrevalnih in hladilnih moči ter za napovedovanje prehodnih toplotnih pojavov pri klimatizaciji opreme v zavetjih in šotorih [3]. Napovedi modela temeljijo na upoštevanju občutene toplote in predpostavki, da so vplivi vlaženja in sušenja zanemarljivi.

V prispevku so prikazane razširitve modela, ki so bile narejene za simulacije zavetij z zakrivno mrežo. Zakrivni sistemi so modelirani kot sevalni ščiti.

0 INTRODUCTION

Shelters and tents are deployed in diverse climates all over the world. Examples include military applications such as command posts, hospitals, latrines, kitchens, computer centers, sleeping quarters, and showers. The construction of these shelters varies from canvas to composite wall sections with external aluminum sheets and internal paper honeycomb insulation. Simulation models can be used for determining the heating and cooling loads for different shelters and tents deployed under various environmental conditions. These results can be used in sizing site-specific environmental control equipment.

Effective heating and cooling for internal shelter environments (temperature and humidity) has become essential for optimum personnel and equipment performance. For example, communications equipment must be maintained within a certain temperature and humidity range in order to avoid damage during startup and operation. An undersized environmental control unit (ECU) could result in unhealthy conditions and equipment failure. An oversized ECU will require an excessively large generator, and will impose a logistics burden.

1 BACKGROUND

In the 1980s BDM International, Inc., produced a Shelter System Assessment Model (SAM) [1] to size environmental control equipment for portable shelters for the U.S. Army. The dependence on electronic equipment in command-and-control shelters has increased substantially, and the types of shelters (size, materials and uses) have also changed since 1980. The recommended ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) methods for determining heating and cooling loads have improved considerably during the past twenty years. Some of the assumptions for the original SAM model are questionable and inconsistent with current ASHRAE recommendations [2].

A new environmental control assessment model has been under development for computing the heating and cooling loads and for predicting the transient thermal performance of air-conditioning equipment in shelters and tents [3]. Model predictions are based on sensible heat considerations under the assumption of negligible humidification and dehumidification influences.

This paper reports the model enhancement made for simulating shelters deployed with camouflage netting. Camouflage systems are modeled as radiation shields.

2 RAČUNSKI MODEL

Stene zavetja so pogosto narejene iz sataste izolacijske strukture med dvema aluminijastima ploščama. Prehod toplote v stenah zavetja ovrednotimo z večvozliščnim modelom. Predpostavimo, da se toplota shranjuje v aluminijastem sloju stene, ki ne predstavlja upora prevodu toplote in da je celoten upor prevodu toplote posledica vgrajene toplotne izolacije, v kateri se toplota ne shranjuje. Predpostavimo tudi, da ima zakrivna mreža (sevalna zaščita) zanemarljivo zmožnost hranjenja toplote. Zato obravnvamo prehod toplote v sevalnem ščitu kot stacionarni problem. Celotni model obravnava zaprt prostor s štirimi stenami, streho, podom in ustrezno zaščito pred sončnim sevanjem.

Kakor je prikazano na sliki 1 sledi, da je absorbirano sončno sevanje enako konvektivnemu toplotnemu toku med okolico in notranjo ter zunanjo površino ščita, dolgovalovnemu sevalnemu toplotnemu toku med ščitom in steno zavetja in dolgovalovnemu sevalnemu toplotnemu toku med ščitom in nebom oz. okolico. Temu ustreza energijska bilanca:

2 NUMERICAL MODEL

The shelter walls are often constructed of a honeycomb insulation structure between two aluminum plates. These walls are modeled using a multi-node lumped-capacity model. The assumption is that all energy storage is in the wall skin (aluminum), which offers no internal resistance to energy flow, and that the insulation offers resistance to energy flow without any energy storage. The camouflage netting (radiation shield) is assumed to have negligible heat capacity. Therefore, the radiation shield is modeled using a steady-state energy balance. The full model provides for an enclosure with four wall surfaces, a roof, a floor and corresponding solar radiation shields.

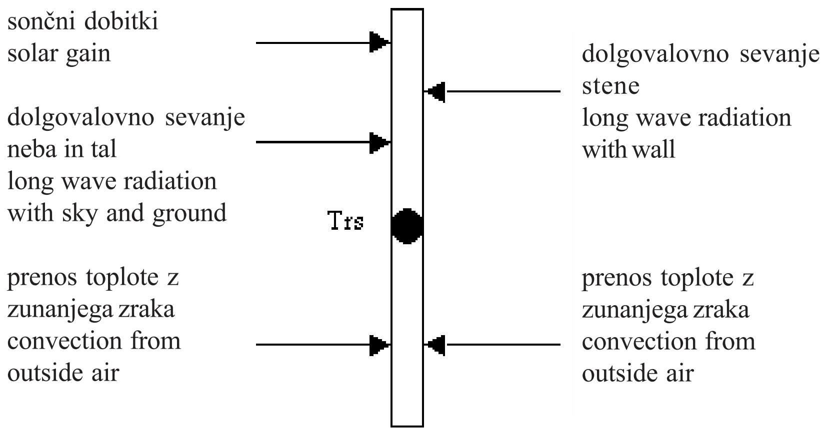
As illustrated in Figure 1, the steady-state energy balance on a radiation-shield node requires that the absorbed solar energy must be equal to the convection with the outside air on each side of the shield, the long-wavelength radiant exchange with the wall, and the long-wavelength radiant exchange with the sky and the ground. The corresponding energy-balance equation is given as:

$$0 = Q_{solar} + 2h_0 A(T_a - T_{rs}) + \frac{\sigma \; A \; (T_{wo}^{4} - T_{rs}^{4})}{\frac{1}{\varepsilon_{rs}} + \frac{1}{\varepsilon_{wo}} - 1} + \varepsilon_{rs}\sigma A(T_{rs}^{4} - F_{ss}T_{sky}^{4} - F_{sg}T_{g}^{4}) \qquad (1).$$

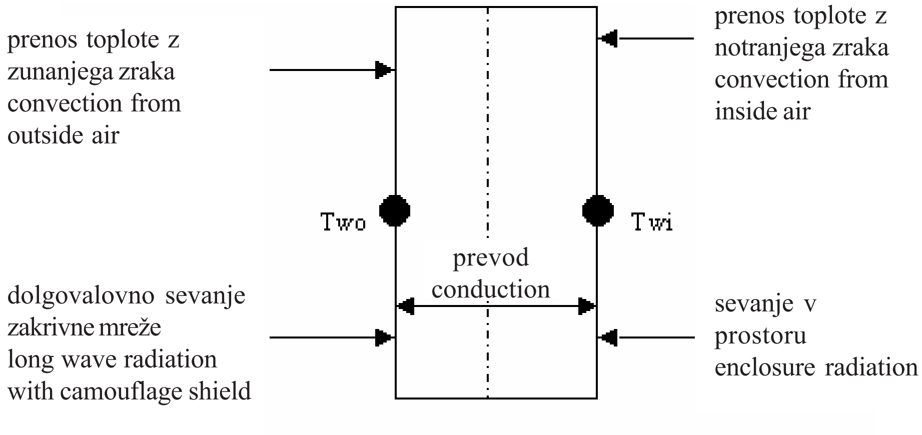
Energijska bilanca v vozlišču zunanje stene upošteva, da je sprememba notranje energije tega elementa enaka razliki toplotnih tokov, v izbranem časovnem koraku. Kakor je prikazano na sliki 2, na spremembo notranje energije zunanjega vozlišča stene vpliva konvektivni prenos toplote na zunanji zrak in dolgovalovni sevalni tok, ki ga stena izmenjuje s ščitom ter prevod toplote med notranjim in zunanjim vozliščem. Ta energijska bilanca je:

An energy balance on the outside-wall node requires that the change in the internal energy of the node must be equal to the net energy into the node at any instant in time. As illustrated in Figure 2, the net energy into the outside-wall node consists of the convection with the outside air, the conduction from the inside-wall node, and the long-wavelength radiant exchange with the radiation shield (camouflage net). This energy balance is:

$$(\rho c V)_{wo} \frac{\Delta T_{wo}}{\Delta \tau} = h_0 \; A(T_a - T_{wo}) + \frac{kA}{L}(T_{wi} - T_{wo}) + \frac{\sigma A(T_{rs}^{4} - T_{wo}^{4})}{\frac{1}{\varepsilon_{rs}} + \frac{1}{\varepsilon_{wo}} - 1} \qquad (2).$$



Sl. 1. *Energijska bilanca vozlišča sevalne zaščite (zakrivne mreže)*
Fig. 1. *Energy balance for the radiation shield (camouflage netting)*



Sl. 2. *Energijska bilanca zunanjega in notranjega vozlišča stene zavetja*
Fig. 2. *Energy balance for the shelter wall*

Enačbo, ki povezuje vozlišče na notranji strani stene, vozlišče opreme v zavetju in vozlišče notranjega zraka so razvili Arthur et al. [3]. Energijsko bilanco za vozlišče na notranji strani zidu lahko zapišemo s spremembo temperature vozlišča v časovnem koraku. Na spremembo notranje energije vpliva prevod toplote v steni ter konvektivni in sevalni prestop toplote z notranje površine stene na zrak in opremo v prostoru. Ta enačba je podana kot:

The equations for the inside-wall node, the internal mass in the shelter and the inside-air node were developed by Arthur et al. [3] and presented here. For the inside-wall node, the energy balance can be described as the change in the internal energy of the node being equal to the net energy flow into the node per unit time. The net energy into the node consists of convective exchange with the inside air, conduction from the outside wall node, and radiant exchange in the enclosure. This equation is given as:

$$(\rho c V)_{wi} \frac{\Delta T_{wi}}{\Delta \tau} = h_i A(T_i - T_{wi}) + \frac{kA}{L}(T_{wo} - T_{wi}) + h_r A(T_{fs} - T_{wi}) \quad (3).$$

Model sevanja v prostoru, ki smo ga uporabili za določitev sevalne izmenjave na notranjih površinah, temelji na delu Waltona [4], kot je navedeno v delu Spitler idr. [5]. Pri tem modelu za vsako površino, ki obdaja prostor, predpostavimo, da seva na namišljeno površino v prostoru, katere sevalnost in temperatura zagotavljata približno enak prestop toplote s površine kakor je ta v dejanskem zaprtem prostoru z več površinami. Ker postavitev električnih naprav v zavetju običajno ni znana, za rešitev običajnih problemov sevanja v zaprtih prostorih, ne moremo izračunati geometrijskih sevalnih faktorjev. Waltonov model upošteva približne vrednosti geometrijskih sevalnih faktorjev, ki zagotavljajo enak sevalni prenos toplote.

Električne naprave v zavetju obravnavamo kot enotno maso, ki izmenjuje toploto z notranjim zrakom s konvekcijo, z notranjo površino sten prostora pa z dolgovalovnim sevanjem. V tem vozlišču upoštevamo tudi sproščanje toplote pri uporovnem gretju delujočih naprav. Ta energijska bilanca je podana v enačbi:

The radiation enclosure model used to estimate the radiant exchange among the inside surfaces was based on work by Walton [4], as given in Spitler et al. [5]. In this model each surface in the enclosure is assumed to radiate to a fictitious surface that has an area, a emissivity, and a temperature giving approximately the same heat transfer from the surface as in the real multi-surface enclosure. Since the layout of the electrical equipment in the shelter is not generally known, radiation configuration factors cannot be calculated for solving the classic radiation-enclosure problem. Walton's model makes approximations for the radiation shape factors and provides for the conservation of the radiant energy in the enclosure.

The electrical equipment in the shelter is modeled as a single mass that exchanges energy with the inside air via convection and with the walls via long-wavelength radiation. The electric energy generation (resistive heating) in this mass is also included. This energy balance is given as equation 4:

$$(\rho c V)_{eq} \frac{\Delta T_{eq}}{\Delta \tau} = h_{eq} A_{eq} \quad (T_i - T_{eq}) + h_r A_{eq}(T_{fs} - T_{eq}) + \dot{Q}_{gen} \quad (4).$$

Sprememba notranje energije zraka v zavetju je enaka toplotnemu toku, ki ga dovedemo ali odvedemo pri ogrevanju ali hlajenju z nadzorno enoto notranjega okolja, prestopu toplote na zrak z notranje površine sten, prestopu toplote s površine električnih

The change in the internal energy of the air in the shelter must equal the heating (or cooling) by the environmental control unit, the convection to the air from all the wall surfaces, the convection from the equipment mass, the sensible heat associated with naprav, občuteni toploti, povezani s prezračevanjem in toplotnemu toku, ki ga oddajajo ljudje. V tem modelu latentne toplotne dobitke zanemarimo. Opisana energijska bilanca je prikazana z enačbo:

the make up (outside) air, and the heat gain from personnel. Latent heat gain is neglected in the current model. The statement of this energy balance is given as equation below.

$$(\rho cV)_i \frac{\Delta T_i}{\Delta \tau} = Q_{ecu} + h_{im} A_{sur}(T_{eq} - T_i) + \sum\nolimits_{all\ surf} (h_i A(T_{wi} - T_i) + Q_{peo} + \frac{\dot{Q}_\infty}{v_o} c_p (T_a - T_i) \quad (5).$$

3 UPORABA MODELA IN REZULTATI

Zgoraj opisane povezave v množici vozliščnih kapacitivnosti so za steno zavetja z notranjo opremo prikazane na sliki 3 kot poenostavljeno električno analogno vezje. Ker smo predpostavili, da ima sevalna zaščita (zakrivna mreža) zanemarljivo zmožnost hranjenja energije, izračunamo temperature zaščite iz energijskih bilanc v ustaljenem stanju. Neznane temperature elementov z zmožnostjo hranjenja energije izračunamo za vsako točko v času z uporabo "koračne" rešitve v povezavi s temperaturami sevalne zaščitne mreže.

Zavetje Version 4 SICPS smo izbrali kot primer, na katerem smo proučevali učinek hlajenja z zakrivno mrežo in brez nje. Toplotno-fizikalni parametri, ki smo jih uporabili v simulacijskem modelu, so podani v preglednici 1. Uporabili smo izračunano sončno sevanje 21. julija ob 14.00 na 36° severne zemljepisne širine (predpostavili smo, da je sevanje v času simulacije nespremenljivo). Predpostavili smo odbojnost tal 20% in čistost ozračja 0,95. Upoštevali smo pretok zunanjega zraka pri prezračevanju 0,019 m^3/s. Za čas simulacije smo upoštevali nespremenljivo temperaturo zunanjega zraka 49 °C. Take razmere v okolju so bile izbrane kot najbolj neugodne in ne predstavljajo nekega določenega okolja.

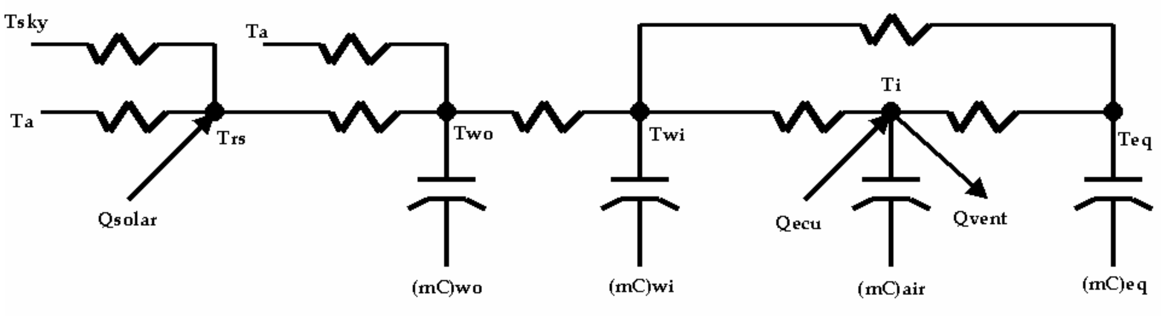
V prvi študiji smo določili čas, ki je potreben, da se zavetje ohladi z začetne temperature 49 °C na 32 °C s hlajenjem z močjo 4 ali 10 kW. Z drugo študijo smo določili velikost hladilnega sistema, ki ga potrebujemo, da se zniža temperatura opreme z 49 °C na 32 °C v 30 oziroma 120 minutah. Omenjeni študiji sta bili izvedeni za zavetje s sevalno zaščito in brez nje. Pri obeh študijah smo predpostavili nespremenljivo začetno temperaturo zavetja, opreme in zraka 49 °C.

3 MODEL IMPLEMENTATION AND RESULTS

The above-described multi-node lumped-capacity relationships for an example shelter wall with internal equipment and air inside the shelter are illustrated in Figure 3 as a simple electric analog network. Since radiation shields (camouflage netting) are assumed to have negligible energy-storage capacity, their temperatures are computed from steady-state energy balances. The unknown temperatures for the elements with energy storage are calculated at each point in time using a "marching" solution combined with the radiation-shield temperatures.

A Version 4 SICPS shelter was selected as an example shelter to study cool-down performance with and without camouflage. The thermo-physical parameters used in the model simulation are given in Table 1. The incident solar radiation was calculated for July 21st at 14:00 hours at latitude of 36° north (and assumed constant for the simulation). Ground reflectance was assumed to be 20% and the atmospheric clearness of 0.95 was used. Outside air at a rate of 0.019 m^3/s was assumed for makeup. The outside-air temperature was held constant at 49°C during the simulation. These ambient conditions were meant to be conservative and not necessarily representative of any particular environment.

The first study was of the time needed to cool the shelter from an initial temperature of 49°C to a final temperature of 32°C using a 4-kW or a 10-kW cooler. The second study determined the cooler size needed to lower the equipment from 49°C to 32°C in 30 minutes and in 120 minutes. The above studies were run for a shelter with and without camouflage (radiation shielding). Both studies were started with the assumption that the shelter, the equipment and the air were at a steady initial temperature of 49°C.



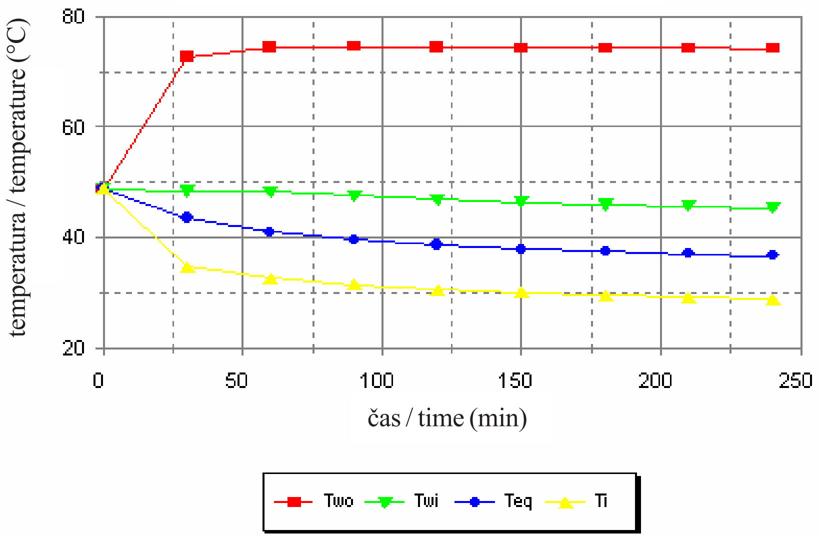
Sl. 3. *Preprosta električna shema zavetja*
Fig. 3. *Simple electric schematic for the shelter*

Preglednica 1. *Izbrani parametri v primeru hlajenja zavetja*
Table 1. *Parameters selected for shelter cooling example*

	zunanje stene outside walls	izolacija insulation	notranje stene inside walls	oprema equipment	notranji zrak inside air
h (W/m^{2}K)	7,0		3,4	45,0	
masa / mass (kg)	136		136	182	8,75
cp (kJ/kgK)	0,92		0,92	1,09	1,00
površina / area (m^2)	25,5		25,5	6,5	
k/L (W/m^{2}K)		2,337			
sevalnost stene zavetja shelter wall emissivity	0,8		0,8		
sevalnost zaščite camouflage emissivity	0,4		0,4		

Preglednica 2. *Potrebna moč hlajenja opreme na želeno temperaturo 32 °C pri prezračevanju z zunanjim zrakom 0,019 m³/s v zavetju brez sevalne zaščite*
Table 2. *Performance for equipment to reach 32°C with 0.019 m³/s outside makeup air in a shelter without camouflage (radiation shielding)*

znižanje temperatur temperature range	čas time	potrebna moč hlajenja required cooling power	temp. notranjega zraka inside-air temperature
49°C do/to 32°C	30 min	6,4 kW	19,6°C
49°C do/to 32°C	120 min	4,6 kW	23,6°C
znižanje temperatur temperature range	moč hlajenja cooling power	potreben čas required time	temp. notranjega zraka inside-air temperature
49°C do/to 32°C	4 kW	nezadostno / unsufficient	nezadostno / unsufficient
49°C do/to 32°C	10 kW	13 min	10,6°C



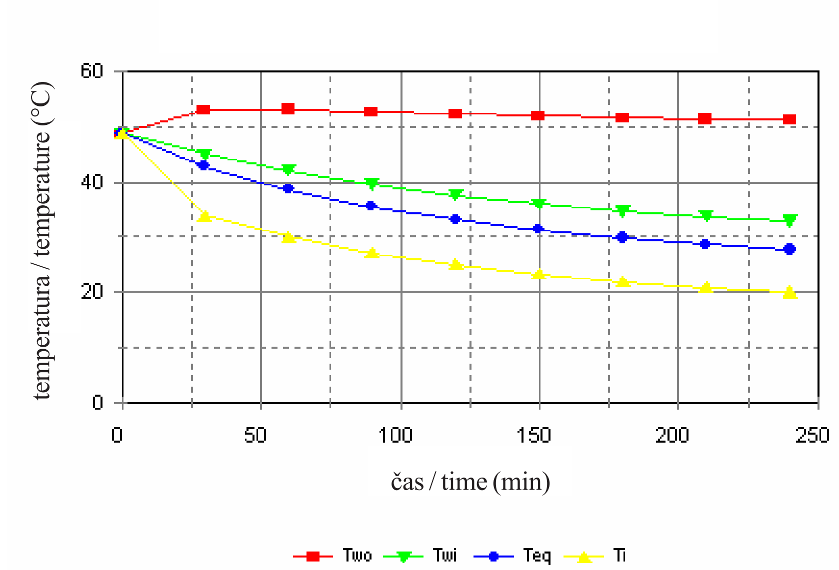
Sl. 4. *Temperature elementov modela SICPS pri hlajenju z močjo 4 kW, prezračevanjem 0,019 m³/s, začetni temperaturi 49°C, brez sevalne zaščite*
Fig. 4. *SICPS thermal performance with a 4-kW cooler, 0.019 m³/s outside air, initial temperature of 49°C, without camouflage*

Pregled rezultatov simulacije za zavetje brez zakrivne zaščite je v prikazan v preglednici 2. Iz preglednice 2 vidimo, da v skladu z modelom hladilnik z močjo 4 kW ni dovolj močan, da bi, pri pogojih simulacije, ohladil opremo v zavetju do želene

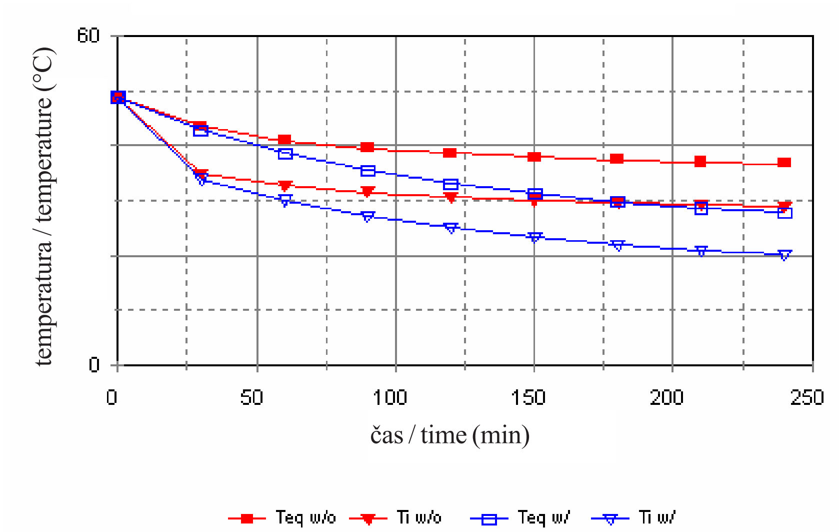
A summary of the simulation results for the shelter without camouflage shielding is given in Table 2. From Table 2, we see that the model predicts that the 4-kW cooler is unable to bring the shelter down to the desired operational temperature of 32°C under the

Preglednica 3. *Rezultati simulacije temperatur opreme pri hlajenju na 32 °C, prezračevanju 0,019 m³/s v zavetju s sevalno zaščito*
Table 3. *Performance for equipment to reach 32°C with 0.019 m³/s outside makeup air in a shelter with camouflage (radiation shielding)*

obseg temperatur temperature range	čas time	potrebna moč hladilnika required AC unit	temp. notranjega zraka inside-air temperature
49°C do/to 32°C	30 min	6,2 kW	19,6°C
49°C do/to 32°C	120 min	4,1 kW	24,1°C
obseg temperatur temperature range	velikost hladilnika AC unit size	potreben čas required time	temp. notranjega zraka inside-air temperature
49°C do/to 32°C	4 kW	140 min	24,4°C
49°C do/to 32°C	10 kW	13 min	10,6°C



Sl. 5. *Temperature elementov modela SICPS pri hlajenju z močjo 4 kW, prezračevanjem 0,019 m³/s, začetno temperaturo 49°C, s sevalno zaščito*
Fig. 5. *SICPS thermal performance with a 4-kW cooler, 0.019 m³/s outside air, initial temperature of 49°C, with camouflage*



Sl. 6. *Primerjava temperatur elementov zavetja SICPS s sevalno zaščito in brez nje med hlajenjem*
Fig. 6. *Comparison of SICPS shelter with and without camouflage during cool down*

temperature 32 °C. Prehodne temperature so prikazane na sliki 4. Pregled rezultatov za zavetje s sevalno zaščito je prikazan v preglednici 3. Iz te preglednice vidimo, da lahko prostor, ki ga hladimo s hladilnim tokom 4 kW ohladimo do želen temperature v 140 minutah. Potek temperature v tem primeru je prikazan na sliki 5.

Iz rezultatov obeh študij lahko ugotovimo, da ima sevalna zaščita na začetku majhen učinek, kar je razvidno s slike 6 pri hlajenju po 60 minutah. Vendar pa je v daljšem času zaščita koristna. Pri namestitvi le-te je temperatura opreme in notranjega zraka pri enaki hladilni moči po 240 minutah hlajenja nižja za 9 °C.

simulated conditions. Transient temperatures are plotted in Figure 4. A summary of the simulation results for the shelter with camouflage is given in Table 3. From this table, we see that the 4-kW cooler can bring the shelter down to the set point after 140 minutes. The temperature histories for this simulation are shown in Figure 5.

From the results of these studies we can see that camouflage has little effect initially, for example, see Figure 6 at 60 minutes. However, in the long term, camouflage is beneficial: Figure 6, at 240 minutes, shows that the equipment mass and the inside-air temperatures are reduced by 9°C when camouflage is used.

4 SKLEP

Razvili smo novi simulacijski model za napoved ogrevanja in hlajenja zavetij, ki ga lahko uporabimo za določevanje spreminjanja temperatur elementov zavetja. Model lahko uporabimo tudi za določitev velikosti NENO. Za zavetje Version 4 SICPS smo izvedli različne simulacije s sevalno zaščito (zakritjem) in brez nje.

4 CONCLUSION

A new heating-and-cooling simulation model for camouflaged shelters has been developed. The model can be used to predict the temperature history of the shelter. The model can also be used to predict the necessary environmental control unit size. Various simulations have been made of a Version 4 SICPS shelter with and without radiation shielding (camouflage).

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7 OZNAČBE
7 NOMENCLATURE

gostota	ρ	kg/m³	material density
specifična toplota	c_p	kJ/kgK	material specific heat
prostornina	V	m³	material volume
debelina stene	L	m	wall thickness
toplotna prevodnost snovi	k	W/mK	material thermal conductivity
koeficient prestopa toplote na zunanji strani stene	h_o	W/m²K	outside-wall convection coefficient
koeficient prestopa toplote na notranji strani stene	h_i	W/m²K	inside-wall convection coefficient
koeficient prestopa toplote notranje el. mase	h_{im}	W/m²K	inside electrical mass convection coefficient
koeficient prestopa toplote za vozlišče opremne mase	h_{eq}	W/m²K	convection coefficient for the equipment mass node
koeficient sevalnega prestopa toplote za notranje površine	h_r	W/m²K	radiation heat-transfer coefficient for the inside surfaces
površina stene	A	m²	wall surface area
površina notranjih električnih naprav	A_{sur}	m²	inside electrical mass surface area
površina vozliščne opremne mase	A_{eq}	m²	surface area of the equipment mass node
temperatura zunanjega zraka	T_a	K	outside-air temperature
temperatura neba	T_s	K	sky temperature
temperatura tal	T_g	K	ground temperature
temperatura notranjega zraka	T_i	K	inside-air temperature
temperatura sevalnega (zakrivnega) ščita	T_{rs}	K	radiation-shield (camouflage) temperature
temperatura vozlišča na zunanji površini	T_{wo}	K	outside-wall surface node temperature
temperatura vozlišča na notranji površini	T_{wi}	K	inside-wall surface node temperature
temperatura opreme	T_{eq}	K	equipment temperature
navidezna temperatura površine po Waltonovi metodi	T_{fs}	K	fictitious surface temperature of Walton's method

sevalnost zunanjega zidu	ε_{wo}		outside-wall emissivity
sevalnost sevalnega (zakrivnega) ščita	ε_{rs}		radiation-shield (camouflage) emissivity
Stefan-Boltzmannova konstanta	σ=5,67·10^{-8}	W/m^{2}K^4	Stefan-Boltzmann constant
sevalni oblikovni faktor površine proti nebu	F_{ss}		surface-to-sky radiation shape factor
sevalni oblikovni faktor površine proti tlem	F_{sg}		surface-to-ground radiation shape factor
absorbirano sončno sevanje	Q_{solar}	W	absorbed solar radiation
dolgovalovno sevanje s stene proti drugim površinam v bližini	Q_{lwi}	W	long-wavelength radiation from the wall to other surfaces in the enclosure
dolgovalovno sevanje z notranje snovi proti preostalim površinam v bližini	Q_{lwm}	W	long-wavelength radiation from the internal mass to other surfaces in the enclosure
uporovno gretje električne opreme v zavetju	Q_{gen}	W	resistive heating of the electrical equipment in the shelter
toplota ljudi	Q_{peo}	W	heat from people
moč grelne/hladilne opreme	Q_{ecu}	W	capacity of heating/cooling equipment
pretok zraka	$\dot{V}_{\infty}$	m^3/s	makeup air-flow rate
gostota zunanjega zraka	ρ_o	m^3/s	outside-air density

7 LITERATURA
7 REFERENCES

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