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APPLICATION POSSIBILITIES OF THE OFF-GRID HVAC SYSTEM OPERATION SOLUTION FOR TEMPORARY SHELTERS IN THE LATVIAN CLIMATE CONDITIONS

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Temporary shelters are extensively used by emergency services (rescue, disaster relief, military response) and other end-users requiring temporary mobile power solutions for different purposes (event organization, vacation homes, summer camps, etc.). The Covid-19 pandemics resulted in an increase of motor homes worldwide sales.

When temporary shelter connection to power grid is impossible, the off-grid liquid fossil fuel generator can be used for electricity generation. Since the liquid fuel supply is often limited, the stock of fuel requires storage that may pose an explosion risk. Quickly installable and energy-efficient ventilation / cooling system with heat recovery is essential to ensure adequate air hygiene and occupants' comfort in temporary structure.

This paper presents a mobile modular electric energy generating unit with photovoltaic (PV) panels for providing temporary shelters (tents) in Latvian climate conditions with heating, ventilation, and air conditioning (HVAC). All calculations were performed using the computer model developed with TRNSYS tool and based on real data from mobile modular energy unit for spring, summer and autumn 2020 and winter 2021. The results show that mobile modular energy unit can be successfully applied for off-grid HVAC system operation of temporary shelters in the Latvian climate conditions.

Keywords: *Emergency energy supply, HVAC, mobile modular energy unit, off-grid, PV, temporary shelters.*

1. INTRODUCTION

By the end of 2019, 79.5 million people, of whom 26.0 million were refugees, had been forcibly displaced due to persecution, conflict, violence, human rights abuses or serious public order [1]. The camps were home to more than 6.6 million refugees and people in refugee-like situations, of whom 4.6 million were in planned / managed camps and about 2 million in self-employed camps [2]. Indoor comfort and HVAC systems efficiency were often ignored in the temporary shelter design process, as they were primarily built to provide safety of camp residents. Studies [3], [4] show that such camps are mostly concentrated in regions with a harsh, often extremely hot climate, and the indoor temperature in shelters can reach 39–46 °C. These data show the need to maintain an appropriate microclimate in temporary shelters. The indoor air quality is essential not only for residential but also for military personnel despite their relatively better physical conditions [6], [7]. Most of the operational energy demand in temporary off-grid structures is accounted for HVAC requirements. During periods of extreme weather conditions, HVAC systems consume up to 60 % of the fossil liquid fuel (diesel) allocated to military forward operating bases [5].

The temporary camps of military bases, disaster relief sites, temporary search, rescue or recreation camps are most often located in areas distant from the power grid. The deployable tents, easy to transport and mount, are most often used as premises. The living indoor comfort conditions of such premises entirely depend on weather. The reality is that disasters, whether human or natural, tend to be unique in terms of shelter budget, availability of materials, etc. which makes it nearly impossible to plan ahead the grid connection of the shelters [8], constant supply of liquid fossil fuel, as well as safe fuel storage conditions.

One of the possible solutions to generate electricity autonomously is the use of off-grid mobile PV system, such as Zerobase Energy’s T-Series system mobile – towable trailer with PV panels and storage battery, and solar PV and hybrid (wind and/or portable generator) input [9]. One more example is a mobile PV-Wind-Battery-Diesel Hybrid System unit, constructed inside a transportable container [10]. The authors [9], [10] proposed that a new generation of mobile solar PV solutions should be more affordable to the community and easier in use.

This paper presents a mobile modular energy generating unit with PV system for the HVAC system operation in temporary shelters.

The unit provides simultaneous supply of electricity, heating and cooling and has a built-in heat recovery device. This quickly installable and energy-efficient ventilation system is essential to ensure adequate air hygiene and occupants’ comfort in temporary structures. The developed working prototype (Fig. 1) is assembled on a common car trailer base and can be towed by a light vehicle. The estimated size of the trailer is the following: width 1.8 m, length 3.7 m, height 1.6 m.

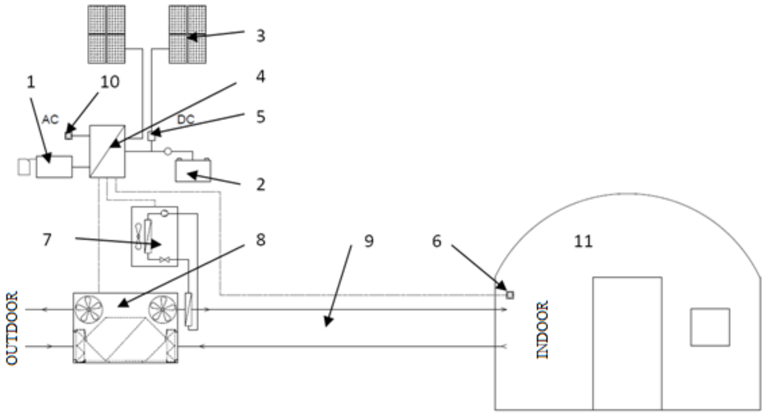
a) operation condition

b) transportation condition

Fig. 1. Mobile modular energy unit.

2. MATERIALS AND METHODS

The developed mobile modular energy unit includes eight photovoltaic cells for power generation. The electricity is converted into thermal energy in the heat supply unit and/or is directly supplied to the consumers. When energy is not consumed, it is stored in the energy storage battery. If necessary, it is possible to start a diesel generator. In order to extend the autonomous life of the mobile modular energy unit and to increase the overall efficiency of the system, heat recovery unit is provided. Heat recovery is an essential part of modern energy efficient HVAC [11]. Unit cooling capacity is ≥8 kW, and heating capacity ≥9 kW. The heat is produced using a highly efficient air / air heat pump compression cycle, which can also provide the consumer with cooling demand. Heat pumps are proved as an energy efficient solution both in hot and cold climate conditions [12], [13] . The control of the mobile modular energy unit is implemented by means of an energy management unit, which is connected to the Internet enabling a remote control. The principal scheme and technical characteristics of the proposed mobile modular energy unit are shown in Fig. 2 and Table 1.



1 – diesel generator; 2 – battery; 3 – PV panels; 4 – inverter; 5 – controller; 6 – consumers' power connector; 7 – heat pump; 8 – air-to-air heat recovery device; 9 – air supply / exhaust channels; 10 – connection to the power supply; 11 – shelter.

Fig. 2. The principal scheme of the mobile modular energy unit.

Table 1. Technical Characteristics of the Mobile Modular Energy Unit

PV Power (Wp)	2400
Inverter Power (W)	Cont. output power at 25 °C = 3000VA / 2400W
Batteries (N - V - Ah)	2 batteries provide: Rated voltage 12.8V Nominal capacity at 25 °C 200 Ah Nominal capacity at 0 °C 160 Ah Nominal capacity at -20 °C 100 Ah Number of cycles at 80 % charge: 2500
Battery Capacity (Wh)	Rated energy at 25 °C 2560 Wh
Dimensions Closed (m)	1.8 x 3.7 x 1.6
Dimensions Opened (m)	4.4 x 3.7 x 1.6
Weight (Kg)	1350

Based on the research carried out by the Department of Heat Engineering and Technology of Riga Technical University [14], it was decided to evaluate the ability of the mobile modular energy unit system to meet the temporary tent need for HVAC operation systems in the climate conditions of Riga, Latvia. All calculations were performed using a computer model (Fig. 3) developed for this purpose with the help of the transient system simulation (TRNSYS) software tool. TRNSYS was chosen because of its extensive component library and simulation capabilities, especially in the field of renewable energy. Its capability was demonstrated in studies [15] (modelling the performance of a solar photovoltaic thermal collector (PVT)) and [16] (simulation of energy systems with PV; for cold climate adding the PVT, floor heating, and a generator for increasing the heat load). The model validation was based on the real modular energy unit operation data. The necessary data were obtained by the energy management software from the sensors installed inside the tent.

The input data for energy simulation are shown in Table 2. Depending on the air temperature in the tent and the desired air temperature according to timetable shown in Table 2, the differential controllers send on/off signals to the heat pump and to the air-to-air heat recovery device. The parameters of a tent in TRNSYS were adopted according to the parameters of the manufacturer's specification (5 m x 4 m x 2.3 m). The U – heat transfer coefficient of a PVC coated fabric [17] is shown in Table 2.

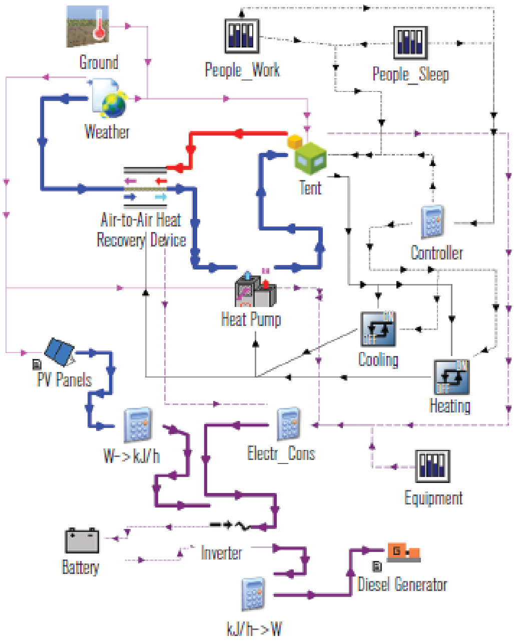


Fig. 3. Computer model.

Table 2. Input Data for Energy Simulation

The input data of tent	
Parameters	**Value**
Roof and wall	U=1.13 W/m^{2}K
Floor	U=0.87 W/m^{2}K
Volume	35.25 m^3
Area	20 m^2 floor; 48.6 m^2 walls and roof
Heat Loss	73.32 W/K
Capacitance	42.3 kJ/K
Weather	Riga, Latvia
Timetable	

Time	**Occupant**		**Heating Temperature (°C)**	**Cooling temperature (°C)**	**Light (W)**	**Equipment (W)**
	Count	**W (met)**				
12 AM–6 AM	5	100 (0.9)	18 ± 2	23 ± 1	-	-
6 AM–10 AM	2	125 (1.1)	18 ± 2	23 ± 1	55	-
10 AM–1 PM	0	-	5 ± 2	27 ± 1	-	-
1 PM–3 PM	5	125 (1.1)	18 ± 2	23 ± 1	55	300
3 PM–8 PM	0	-	5 ± 2	27 ± 1	-	-
8 PM–10 PM	5	125 (1.1)	18 ± 2	23 ± 1	55	40
10 PM–12 AM	5	100 (0.9)	18 ± 2	23 ± 1	-	-

Table 3. Mobile Modular Energy Unit Parameters

Parameter	**Value**
PV Panels	
Azimuth of surface, slope of panel	South, 0^0
Power	400 Wp
Voltage at max Power point	33.21 V
Current at max Power point	9.23 A
Module area	1.46 m^2
Number of modules	6
Heat Pump	
-20 °C outside DBT*	Heating capacity 3.52 kW
5 °C intake DBT	Heating power 1.76 kW
29 °C outside DBT	Cooling capacity 3.50 kW
22 °C intake DBT	Cooling Power 0.95 kW
Air-to-air heat recovery device	
Heat recovery sensible effectiveness	0.797
Heat recovery latent effectiveness	0.889
Ventilation flow rate	350 m^3/h
Ventilation fan total power	150 W

Parameter	**Value**
Battery	
Cell energy capacity	200 Ah
Cells	8
Charging efficiency	0.92
Max charge voltage per cell	2.8 V
Inverter	
Regulatory efficiency	0.98
Inverter efficiency	0.94
High limit on FSOC **	100 %
Charge to discharge limit on FSOC	0 %
Inverter output power capacity	2400 W
Upper limit on FSOC for grid charging	100 %
Current for grid charging of battery	100 A
Diesel generator	
Rated power	2.0 kW
Max power	2.4 kW
Min power	0.6 kW

* dry-bulb temperature

** fractional state of charge

It was assumed that the model would take into account heat production from human and lighting and the electricity consumption of equipment (see Table 2). The maximum possible electrical load was approximately 2.3 kW. There was no air recirculation inside the shelter and ventilation was provided only while heating. As the simulation results showed, the supply air (at an airflow rate of 350 m^3/h) needed to be cooled to a comfortable temperature by 10–15 degrees in summer. In winter, the supply air was heated 30–35 degrees above the outdoor temperature. The heat pump power was set 15 degrees above indoor / outdoor temperature difference. While operating in winter mode, the diesel generator was connected to provide a system with additional electricity.

The components and parametrs of mobile modular energy unit are presented in Table 3.

3. RESULTS AND DISCUSSION

Simulations were made for one-year period (four seasons), for Riga, in the Latvian climate conditions, using both climatic databases and the operational real data of the mobile modular energy unit. Table 4 presents real operation data of the mobile modular energy unit.

Table 4. Operational Data of Mobile Modular Energy Unit

	Winter	Spring	Summer	Autumn
Electricity consumed (kWh)	1,001	4,22	5,20	354
Diesel generator produced electricity (kWh)	1,173	210	60	370
Diesel consumed (l)	378	70	20	119
Diesel generator work time (h)	955	193	55	298

Approximately 60 % of the heat supplied from the exhaust air in winter, in spring and autumn is recovered by an air-to-air heat recovery device.

The maximum diesel fuel consumption is in the winter period. During other seasons, (in most cases) the PV produced electricity is greater than the amount of electricity consumed by a HVAC system per day.

Table 5. Statistical Results

		Electricity consumption per day, kWh	Difference, % (PV produced electricity/electricity consumed per day)	Airflow of occupied shelter, kg/h	Diesel fuel consumption, l/day
Winter	Min	4.23	1	103	1.43
	Max	27.25	81	352	8.17
	Mean	11.12	16	173	4.20
	SD*	4.93	17	50	1.37
Spring	Min	1.31	16	4	0.00
	Max	12.34	741	168	4.16
	Mean	4.59	269	75	0.76
	SD	2.53	203	44	1.01
Summer	Min	1.12	8	4	0.00
	Max	9.50	962	118	2.20
	Mean	3.15	320	53	0.30
	SD	1.88	180	36	0.98
Autumn	Min	1.29	3	3	0.00
	Max	13.44	474	171	5.07
	Mean	3.89	128	65	1.31
	SD	2.46	131	40	1.40

* standard deviation

Table 5 presents one-year simulations based on real energy data statistical results of electricity consumption/production of the mobile modular energy unit. For simulations, it was assumed that the airflow was 4.0 l/s per person [18]. Taking into account that the Latvian construction standards neither determine the required minimum amount of ventilation air, nor provide indications of the values that should be adopted, the regulations of other countries were applied.

Simulations showed that the airflow of the occupied shelter was 4.8–16.3 l/s per person in winter and 0.2–7.8 l/s per person during other seasons. For this type of shelters (tent), the airflow rate strictly depends on the outside temperature. In summer, the system mostly operated without a diesel generator because electricity generated by PV and stored in batteries was completely sufficient to provide HVAC system operation.

To demonstrate the PV panel impact, the simulations without PV were performed only for off-grid operation of the shelter using the diesel generator (Table 6).

Table 6. PV panel Impact

		Produced electricity, kWh	Diesel fuel consumption, l		Diesel generator work time, h	
Winter	Without PV	0	416	-	1,054	-
	PV	132	378	-9 %	955	-9 %
Spring	Without PV	0	241	-	632	-
	PV	797	70	-71 %	193	-69 %
Summer	Without PV	0	300	-	792	-
	PV	1203	20	-93 %	55	-93 %
Autumn	Without PV	0	205	-	506	-
	PV	286	119	-42 %	298	-41 %

According to Table 6, it can be concluded that for the mobile modular energy unit with PV panels, which put in action the HVAC system, the diesel generator would reduce diesel fuel consumption to 71–93 % in the spring and summer period and to 9 % in winter in the Latvian climate conditions. These are very good indicators, considering that, when the energy unit operates using PV, only 20 l of diesel fuel are needed during the whole summer season.

4. CONCLUSIONS

Comparing the amount of energy required for the HVAC system of the shelter, the modular energy unit can provide autonomous work by 50 % during the year while operating only the PV panels, without the fossil fuel generator. If we accept that temporary shelters operate only in the summer season, the modular energy unit can provide autonomous work by 93 %. Table 7 presents simulation data for cities with similar climate conditions.

Table 7. Summary of Annual Operation of Mobile Energy Unit

Town	Electricity, kWh				Energy, kWh		Time, h		
	Total required	PV produced	Additional required	Heat recovered	Heat supplied	Cool supplied	Heating	Cooling	Diesel work
Stockholm	1968	2313	1639	5585	3669	392	1626	115	1369
Riga	1989	2268	1674	5571	3616	457	1600	134	1460
London	944	2169	577	1895	1152	559	609	165	412

The amount of electricity generated annually by the PV panels of the mobile energy unit is higher than the demand. Therefore, the optimal heating and cooling algorithms for different applications should be further explored – different types of shelters, their sizes, thermal properties, equipment load and planning, required internal temperature and airflow rate depending on different seasons. Additionally, the real operation data received within only one year is insufficient for creation of a reliable computer model. For better model validation, the second year of data processing of the mobile energy unit use in real conditions has already begun.

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