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Temperature and time impact on food safety in domestic refrigerator

Andrej **OVCA***, Mojca **JEVŠNIK**

ABSTRACT:
The domestic refrigerator is indispensable kitchen device and very important link for food safety in food supply chain. Various studies of consumers' food safety knowledge and practices show consumers' insufficient knowledge about the importance of cold chain maintaining and carelessness by handling with foodstuffs. By consideration of fact that recommended time in which chilled foodstuffs are stored at required temperatures in case of electric power failure vary from two to six hours, it is necessary to gain information about internal temperatures of selected foodstuffs after power failure of domestic refrigerator at different environmental conditions. Measurements of selected foodstuffs internal temperatures in domestic refrigerator in case of electric power failure were done. The research includes different refrigerator exterior and interior conditions. The results have shown impact of exterior ambient temperatures and different degrees of refrigerator loading on internal temperatures of selected perishable foodstuffs' while different frequencies of door openings did not correlate with internal temperatures of selected perishable foodstuffs. The biggest internal temperature difference after six hours of electricity cut-out appears by cream in case of empty refrigerator and high ambient temperatures. The opposite situation appears by frankfurters in case of full refrigerator and low ambient temperatures. Results pointed out the need upon reorganization of methods used for consumers´ education and better cooperation between consumers´ and producer of cold appliances.

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KEY WORDS:
Food safety, Good housekeeping practise, Domestic refrigerator, Power failure

University of Ljubljana,
Faculty of Health Sciences,
Department of Sanitary Engineering,
Poljanska 26a, SI-1000 Ljubljana,
Slovenia
Tel: +386 1 300 11 82,
Fax: +386 1 300 11 19,
E-mail: andrej.ovca@zf.uni-lj.si

* *corresponding author*

INTRODUCTION

The refrigerator is a common and one of the most popular household device in the developed world and very few households do not own a refrigerator or fridge-freezer for the storage of chilled foodstuffs [1,2]. There are now about 1 billion domestic refrigerators worldwide and this is twice as many as 12 years ago [3]. Jackson and others [4] reported that foodstuffs which are stored at low temperatures (chilled and frozen foodstuffs) and products, which can be consumed without further heat treatment, represent more than 60 % of typical shopping basket of an average European consumer. Consumer food safety partly depends on temperature control throughout all stages in the food supply chain: production, transport, storage, retail display and domestic refrigeration. Maintaining a cold chain is one of important preventive steps for ensuring food safety and temperature is one of key parameters, which effect growth of microorganisms and their survival in food. If perishable foodstuffs are not stored at required temperature the process of spoiling starts and if these foodstuffs are also secondary contaminated, pathogen microorganisms, which are causing food borne illness, can grow. Various studies [5,6,7,8,9,10] show consumers´ insufficient knowledge about the importance of cold chain maintaining and carelessness by handling with foodstuffs. Food safety risk is also presented at the last step before foodstuffs reach consumers in retail when the cold chain is frequently broken [11,12].

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Numerous domestic refrigerators are increasing electric energy consumption. Worldwide energy consumption has been increasing rapidly, in fact almost exponentially, since the industrial revolution; and this increasing trend of energy consumption has been accelerated by the improvement of the quality of life, that almost directly relates to the amount of energy consumption [13]. One of reasons for more frequent cut-outs of a circuit in near future could be sustained energy demand, uncertainty over future fossil fuel reserves, and increasing dependency on a few geopolitically unstable regions, cause serious concerns over energy security [14]. Another reason for cut-outs of circuit are extreme climate conditions which can also interrupt electricity supply almost unannounced. There exist different recommendations from different institutions like Institutes for public health, government authorities, food inspection agencies, nongovernmental associations and after all from producers of cooling appliances, which warn consumer about safety of foodstuffs in domestic refrigerator in case of electric power failure. The recommended time in which, chilled foodstuffs are stored at required temperatures in case of power failure vary e.g. from 2 to 4 hours [15], 4 hours [16,17], from 4 to 6 hours [18]; by consideration of some preventive actions e.g. avoid opening the refrigerator door. Majority of these recommendations do not take into consideration all other factors like ambient temperature, frequency of door openings, degree of loading and product arrangement in the refrigerator.

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METHODS

A static household refrigerator (single-door) without ventilation and freezer compartment, with three glass shelves and vegetable storage tray was used (width x height x depth: 60 cm x 85 cm x 60 cm; net volume: 156 L; number of shelves: 3; year of manufacturing: 2006). The thermostat setting before cut-out of circuit was set on position four on seven point scale during the research, which included different refrigerator interior and exterior conditions (Table 1).

Table 1:
Refrigerator interior and exterior conditions during the research.

Refrigerator interior conditions	Door openings	Refrigerator exterior conditions
Empty refrigerator with only 4 selected perishable foods	Without	*T [S]* = 30.6 ± 0.9 °C *T [W]* = 18.5 ± 0.4 °C
	Every two hours	
	Every hour	
Partially full refrigerator	Without	
	Every two hours	
	Every hour	
Full refrigerator	Without	
	Every two hours	
	Every hour	

Legend:
T – average value of ambient air temperature; *[S]* – simulation of summer temperatures;
[W] – simulation of winter temperatures.

Refrigerator was placed in experiment room (Length: 470 cm x width: 225 cm x height: 310 cm) on fourth floor of four-floor building. It was placed 10 cm from the wall. In the experiment room any other source of heat was not present. Selected perishable foodstuffs were: cottage cheese (250 g) in original plastic container, cream (250 mL) in original tetra Pac package, hash meat (800 g) in polyvinyl bag and frankfurters (350 g) in original plastic foil. Cottage cheese was placed on the top shelf, cream on the middle shelf and hash meat on the bottom shelf. All three were placed as close as possible to the refrigerator door with intention to observe the most critical parts of refrigerator, regarding temperature conditions. The frankfurters were placed in the vegetable storage tray with the intention to observe the internal temperature of food in this area of refrigerator. By different degrees of loading, refrigerator was filled with packages, where single package was filled with mixture of water (940 g) and gelatine (60 g). The mixture was first placed in models (width: 15 cm x height: 20 cm x depth: 4 cm) and then after 12 hours in the refrigerator putted in plastic bags (simulation of packing material) which were vacuumed. The packages were used to simulate different degrees of refrigerator load. Their function was to provide thermal ballast and fill up space. At partially full refrigerator 14 of this packages were used, four on each shelf and two in vegetable storage tray. At

The investigator did the door openings manually. In all cases the time from cut-out of a circuit until the end of the measurement was 6 hours.

full refrigerator 28 of these packages were used, eight on each shelf and four in vegetable storage tray. Before cut out of circuit, selected foodstuffs and packages, which were used to simulate different degrees of loading spent 24 hours in refrigerator by its normal operation. Different ambient temperatures were assured with air condition system. Air condition system was placed under the room ceiling and had no direct impact (air flow) on the refrigerator. During the research different internal and external parameters were observed (Table 2).

Table 2:
Internal and external parameters observed during the research.

Parameter	Unit	Time interval
Ambient temperature in experiment room	*°C*	30 min
Internal temperature of selected foodstuffs	*°C*	5 min
Time of single door opening	*s*	10s (90 ° angle)
Time interval of simulated power failure	*h*	6h

The investigator did the door openings manually. In all cases the time from cut-out of a circuit until the end of the measurement was 6 hours. For ambient temperature measurements Testo 605-H1 and for food internal temperature measurements Testo 177-T4 calibrated thermometers were used. Testo 605-H1 is a temperature & humidity instrument, with measurement range -20 °C to +50 °C, resolution 0.1 °C, accuracy ±0.5 °C. Testo 177-T4 thermocouple data logger has up to 4 external temperature probe connections for simultaneous temperature measurement at different sites and in different time intervals. The measurement range is -200 °C to +400 °C , resolution 0.1 °C, accuracy by -100 °C to +70 °C is ±0.3 °C. By internal temperature measurement thermocouples were placed in the center of foodstuffs.

There was no significant difference by different frequencies of door openings which is evident in Figure 1.

RESULTS

Different ambient temperatures and different degrees of loading have shown impact on internal temperatures of selected foodstuffs while different frequencies of door openings did not (Figure 1). The biggest internal temperature difference after six hours of electricity cut-out appears by cream in case of empty refrigerator and *[S]* ambient temperatures. The opposite situation appears by frankfurters in case of full refrigerator and *[W]* ambient temperatures.

There was no significant difference by different frequencies of door openings which is evident in Figure 1. If we look at worst possible conditions (empty refrigerator, foodstuffs as close as possible to the refrigerator door and high *[S]* ambient temperatures) there is less than 0.5 °C difference

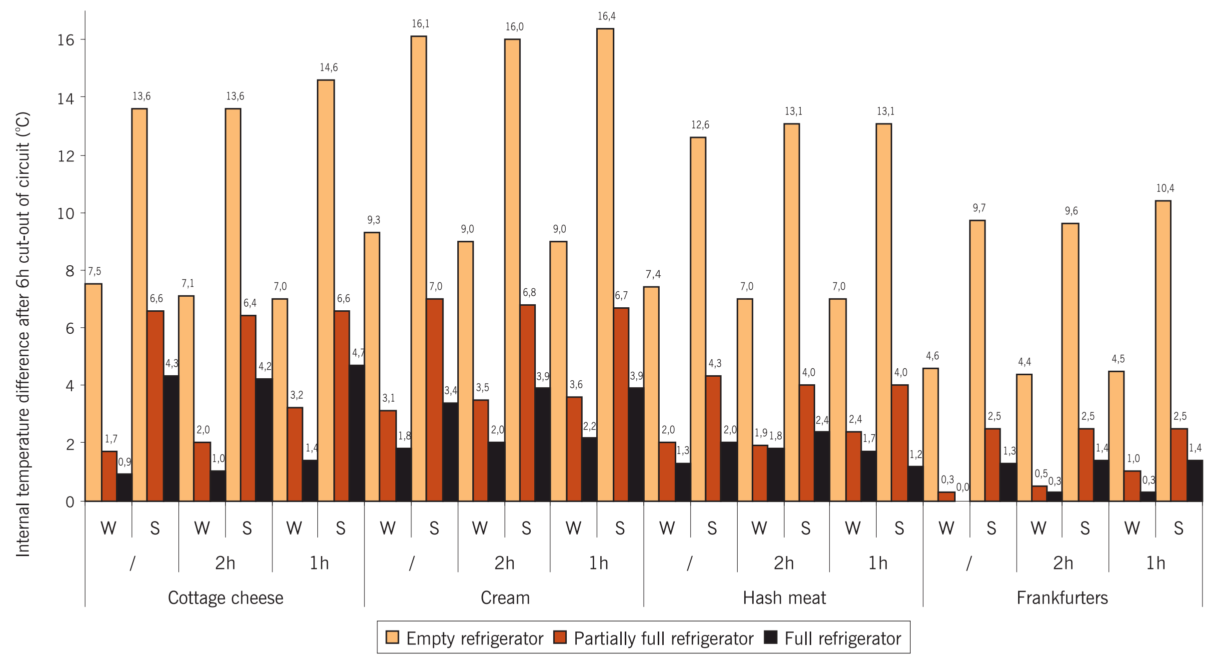

Figure 1:
Internal temperature differences (°C) of selected foodstuffs after 6h cut-out of circuit by different ambient (***[S]*** and ***[W]***) temperatures, different frequencies of door openings and different degrees of loading.

Legend:
/ – zero door openings;
2h – door openings every two hours;
1h – door openings every hour;
[S] = 30.6 ± 0.9 °C;
[W] = 18.5± 0.4 °C.

between zero door openings and door openings every hour. The situation is very similar by lower ambient temperatures and by different degrees of load. In some cases, like cream, temperature differences by door openings are some tenths lower than in case without door opening.

Differences according to different degrees of refrigerator load can be explained with physical characteristic of water (thermal conductivity), which represents 94 % of packages used to provide thermal ballast and to fill up space in refrigerator. By all observed foodstuffs the smallest difference of internal temperature in case of full refrigerator and by lower *[W]* ambient temperatures can be observed (Figure 1). The opposite situation can be observed in case of empty refrigerator and by higher *[S]* ambient temperatures (Figure 1). It should be noted, that frankfurters were placed in vegetable storage tray, which is physically separated from the rest of refrigerator interior.

In Figure 2 six hours movement of internal temperatures by different ambient temperatures in case of partially full refrigerator without door openings can be observed. Results presented in Figure 2 clearly show the impact of external ambient temperature on internal temperatures of selected foodstuffs after cut-out of circuit. Gentler sloped curve by lower *[W]* ambient temperatures then by higher *[S]* ambient temperatures can be observed. In spite of same conditions also differences between selected foodstuffs can be observed. Smaller internal temperature difference between *[S]* and *[W]* case in Figure 2b (3.9 °C) in comparison to Figure 2a (4.9 °C) after six hour cut out of circuit, could be result of different structure of foodstuffs used. Even smaller internal temperature difference between *[S]* and *[W]* case after six hour cut out of circuit in Figure 2c (2.3 °C) could be the result of bigger amount of hash meat compared to other foodstuffs used. The smallest temperature difference

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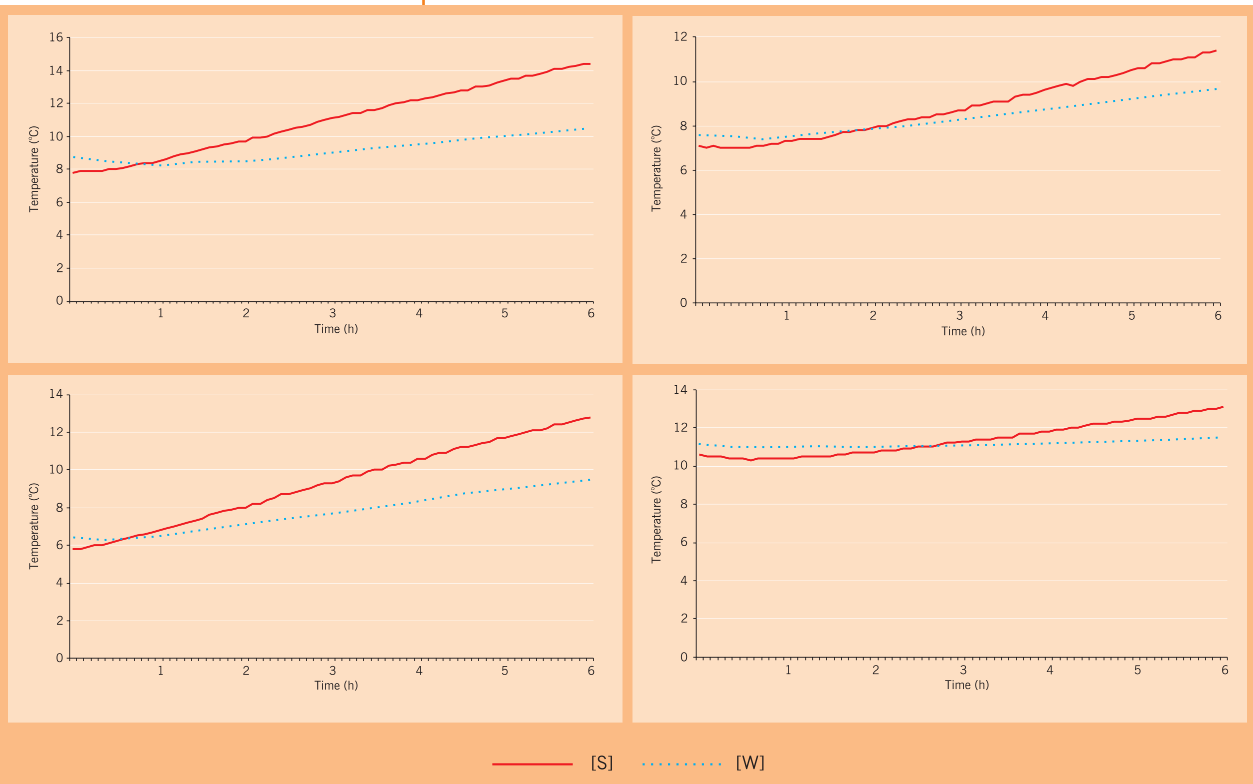

Figure 2:
Comparison of internal temperatures movement of (a) cottage cheese (b) cream (c) hash meat and (d) frankfurters in case of partially full refrigerator without door openings by high *[S]* and low *[W]* ambient temperatures after 6h cut-out of circuit.

Legend:
[S]= 30.6 ± 0.9 °C; *[W]*= 18.5 ± 0.4

(2.2 °C) between *[S]* and *[W]* case after six hour cut out of circuit can be observed in Figure 2d (frankfurters), which were placed in vegetable storage tray. The vegetable storage tray is the lowest part of the refrigerator but it is physically separated from the rest of refrigerator interior with plastic container and that barrier as it can be observed soothes temperature oscillations. In some cases like foodstuffs by lower *[W]* ambient temperatures presented in Figure 2 it can be seen that internal temperatures after the cut-out of circuit first drop and then after one hour start to grow. That could depend on working program of refrigerator (compressor "on" and "off" cycles). If electricity is cuted-out at time when refrigerator is cooling (compressor "on") then internal temperature is still dropping. If electricity is cuted-out at time when compressor is not working (standby position) the internal temperature starts to grow earlier. This phenomenon occurs because at the moment before the compressor starts, the evaporator is at its highest temperature [19].

The very similar situation like presented in Figure 2 can be observed by different door openings. There is some difference according to different degrees of loading regarding to higher (empty refrigerator) or lower (full refrigerator) final temperature after 6 h cut-out of circuit.

DISCUSSION

We estimated that in case of power failure ambient temperature and degree of loading affects internal temperature of selected foodstuffs while frequency of door openings does not. James and Evans [20] assert that the ambient temperature does not exert an effect on the refrigerator temperature. That may be true in case of working refrigerator, but as it can be seen from results in this research, that is no longer true in case of power failure. Most people maintain a temperature of 17 °C – 23 °C in their homes and refrigerators are designed for use in these conditions [20], but in case of cut-out of circuit beside refrigerator also heating or air condition system stop to operate. In such case ambient temperature depends on climate conditions. Different ambient temperatures in this research simulate different time of season or different parts of the world. As shown by Nauta and others [21] in northern European countries refrigerator operating temperatures are usually lower than in southern countries and so consumers in southern parts of Europe take much more microbiological risk for their health than consumers in northern parts of Europe.

Parameter with the least impact on internal temperatures of selected foodstuffs is frequency of door openings. Reason for such situation could be to small interval (10 s) of single door opening. By choosing interval of single door opening test standards for household refrigerating appliances were considered. By chosen time intervals between door openings greater impact on internal temperature of selected foodstuffs was expected. No impact of door opening frequency is maybe not surprising, since the door openings were so infrequent. As shown by Laguerre and others [22] in everyday life frequency of door openings is $<$10 times/day in 19 %, 10 to 20 times/day in 43 % and over 20 times/day in 38 % (N =119), but that considers normal operating of domestic refrigerator. We have avoided more frequent door opening while recommendations for consumers handling in case of electric power failure are recommending to avoid acts like door opening during electric power failure.

High internal temperatures before the cut-out of the circuit (Figure 2) can be attributed to the position of selected foodstuffs (as close as possible to the refrigerator door), to the thermostat setting and as shown by Baar and others [23] to the horizontal temperature gradient (2 °C – 2,3 °C) which appears in refrigerators without air circulation and without built-in freezing box at the top. Thermostat setting on position four on seven point scale was chosen while foodstuffs were freezing by lower settings downwards from seven in empty refrigerator. In refrigerators without ventilation like in this case, strong temperature heterogeneity is often observed with warm zones, which cause microbiological risk and cold zones, which cause freezing risk. So it is very important that consumers know the position of this zones, so that foodstuffs can be placed correctly [24]. But as shown by James and others [1] surveys about consumer handling and also survey done by Ovca and Jevšnik [10] show that consumers usually believe that the coldest location is the top shelf. Beside the bottom also along the back wall cold zone appears. When the refrigerator is loaded, the temperatures of products located near the evaporator are lower than

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We have to consider micro-organisms as described by Jay and others, which grow well at refrigerator temperatures and cause spoilage already at 5 °C – 7 °C, relative humidity of refrigerator environment and also eventually presence of other micro-organisms that are either inhibitory or lethal to pathogens.

located near the door [24]. So it is more proper to store perishable foodstuffs near the back wall. From results obtained in this research it is difficult to predict how long foodstuffs in case of electric power failure are still safe from microbiological point of view. We have to consider micro-organisms as described by Jay and others [25], which grow well at refrigerator temperatures and cause spoilage already at 5 °C – 7 °C, relative humidity of refrigerator environment and also eventually presence of other micro-organisms that are either inhibitory or lethal to pathogens. As shown by James and others [1] it is clear that many refrigerators throughout the world are already running at higher temperatures then recommended. Also in our case internal temperatures before cut-out of circuit were higher than recommended. To get exact prove of food safety after electric power failure of domestic refrigerator, microbiological analysis should be than in the future.

CONCLUSIONS

Because of different recommendations for consumers presented at introduction part and many variations in domestic refrigerators, which were presented in this research, reorganization of methods used for consumer education is proposed. In spite of creating recommendations for consumers how long foodstuffs are still safe after the electric power failure of domestic refrigerator, it is better to educate them when and in which cases they should reject foodstuffs from domestic refrigerators especially perishable foodstuffs. One from lot of different possibilities is incorporation of this topic in to refrigerator producer manuals. The content of this topic should not be abandoned to the producers of cooling appliances only. The attitudes of consumers towards food safety and their practices concerning food are themes of interest to food producers and retailers, public authorities and health educators [26.]. Here institutions like Institutes of Public health should give their contribution or this topic should be regulated on national or even better on international level.

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In this research only one type of domestic refrigerator was used and therefore it may not be appropriate to generalize the results. There are a lot of possibilities of future research within this type of refrigerator (different choice of foodstuffs, different arrangement of selected foodstuffs, different arrangement of test packages, different thermostat settings, different positions of thermocouples, etc.) and also examination of different refrigerator types (different volumes, with ventilation, with freezer compartment, etc.). Consumers' knowledge about issue discussed in our article is also of interest.

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