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RESEARCH ARTICLE

Climate Conditions in ISO Container Shipments from Hungary to South Africa and Asia

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Abstract

The aim of this paper is to provide useful information about climate conditions of transcontinental shipments from Hungary and compare them to the climate profiles of conditioning standards. The climatic environments inside ISO intermodal containers carrying automotive products to three different destinations in India, China and South Africa were measured. All three recorded surveys contain temperature and relative humidity data while the containers were stored outdoors and indoors and travelled on truck, rail and ship. The measured data was analyzed and mean statistical values of daily temperature and RH shifts were determined for each route. The recorded data shows that 50 % of maximum temperature and RH shifts occurred in the EU continent. Temperature and relative humidity distribution as a function of cumulative percentages [%] of the duration of total shipping was also determined and compared to the climate profiles of conditioning standards. It shows that peak temperature and RH ranges occur mostly in the defined duration of conditioning testing time.

Keywords

temperature, relative humidity, packaging, ISO container, transcontinental shipment

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1 Introduction

After the regimes changed in 1989 Hungary joined the global economy. It provided Western European and US companies to build new or scale-up existing production capacities in order to take advantage of lower costs and talented manpower (Eurostat, 2017). Due to its geographical location most of the goods transported from Hungary use multiple modes of transport (ship, rail and truck). A significant increase in global trade could be observed; thus there has been an increase in maritime shipping as well. Here it has to be mentioned that about 51 % of EU trade in goods with non-EU countries was carried by sea in 2015 (UNCTAD, 2016). In today's world of maritime shipping freight forwarders, the transportation companies prefer ISO containers, as they are easy to handle and transfer between various modes of transport (truck, rail and ship). In 2015 the total containerized trade across the main maritime shipping routes increased by 2.4 percent to reach 175 million TEUs (the equivalent of 1.69 billion tons). To serve this increasing need 211 new container ships were built in 2015. That year set a historical record in the building of container ships in terms of container-carrying capacity (UNCTAD, 2016).

Due to the above-mentioned conditions distribution environments are becoming more complex and these dynamic inputs during distribution can cause damages in packaged products. The packaging engineers need to focus on these new challenges in this region. When packaging is prepared for a longer period of shipping, especially for transcontinental shipping, every detail must be carefully considered regarding the possible physical and climatic events. As the products travel for weeks or months, they cannot be damaged during the journey because they cannot be easily replaced when they arrive at their final destination. This in turn will cause a delay in the production. The packaging engineers must understand and meet the requirements and hazards of various forms of shipments, which originate from this region. In addition to creating the best protective packaging they have to take into consideration the costs in order to get optimal logistics-packaging expenses (Böröcz, 2009). One of the primary sources of damages during maritime shipping is corrosion but climatic stresses can cause mechanical damage for instance by reducing the compression strength of a corrugated box until it eventually collapses (Twede et al., 2015). This environment is also conducive to corrosion mainly on products that have metal surfaces, hidden areas or to those equipped with electrical parts. An additional problem is the application of water-soluble adhesives such as glue used on the joints of linerboard and fluting of corrugated fiberboard. Since this type of packaging device is often used it is very important to explore the harmful effects on it, such as long-term shipping and/or storage under load, high temperature and humidity conditions, high humidity, and longer cycles of high/low humidity.

This paper focuses on climate conditions of overseas shipments and its aim is to provide packaging engineers with useful information about climate conditions of transcontinental shipments. The general results can also be used as tools to minimize or eliminate damages during shipping and give a helping hand to achieve better packaging protection and an optimal solution. In the study temperature and relative humidity levels (RH) were monitored and recorded using three different multi-modes of shipping that originated from Hungary (HUN) to the Republic of South-Africa (ZAF), China (CHN) and India (IND), respectively. These values were then analyzed and presented with comparative purposes to the standard (pre)conditioning requirements.

2 Climatic environment during shipping and testing

Packaging engineers usually evaluate historical data, temperature, relative humidity and safety factors to protect against the expected conditions using following:

- Climate databases and climate distribution maps
- Previous papers on this topic
- Research undertaken by the shipper
- Recommendation from packaging test standards.

Organizations and researchers have published several climate databases (National Oceanic and Atmospheric Administration, WorldClim), climate distribution maps (Kottek et al., 2006) and classifications of world climates (United States Department of Commerce, 1991). The potential average temperature and humidity values can be estimated based on these but the real values and the minimum and maximum values cannot. Another problem is that this data regarding only the outer climate does not give accurate information regarding the climate conditions in the container.

Previous papers on this topic are very limited in the aspect that the departing and destination location is Central Europe. One such study (Singh et al., 1993) monitored ships carrying goods from various ports in Central America to North America and Northwestern Europe in 1993. Leinberger (2006) collected and reported data from Xerox Corporation shipments in 2006 and monitored the climate conditions from Nagoya (Japan) to Portland (Oregon, USA) and from Yokohama (Japan) to Memphis (Tennessee, USA) with an additional land journey from California to Tennessee. BAM (Federal Institute for Materials Research and Testing), in 2006, monitored temperature in ISO containers on a return shipment between Hamburg (Germany) and Singapore (Bethke et al., 2013). Singh et al. (2012) instrumented and monitored two shipments for temperature changes from India to USA in 2012. In 2012, Marquez et al. (2012) published a research paper about container temperatures in wine shipments between Australia and the USA. In 2017, Dramas (2017) also monitored overseas shipments that originated from France and had a final destination in Montreal. Only one paper, by Böröcz et al. (2015), partly analyzed the climate environment in Central Europe, this was for shipments from Hungary to South Africa, but the observed freight was an LTL shipment unit not a containerized one. It has to be mentioned here that a complex predictive laboratory climatic stress model was also developed using data of 500 meteorological stations of Europe by Kubeš (1990). Obviously, each company has the right to monitor their shipping routes to get really useful, first-hand data regarding the climate and the physical environment. However, on the other hand, it is an expensive investment, which pays-off only with long-term supplier relationships and/or within extremely sensitive and/or expensive product categories.

The introduced methods mentioned above can give a helping hand to engineers during the transport packaging design process. Packaging standards can be used to test, check, evaluate or validate the developed packaging system. These guidelines always contain conditioning or atmospheric pre-conditioning tests along with or before the mechanical tests. The temperature and relative humidity values can also be used during the developing process too. Table 1 contains these values from the relevant standards and standards group.

3 Materials and methods – the survey

3.1 Travel routes and handling transport equipment

Three shipments were instrumented and monitored for temperature and humidity changes for different dates and times. The starting dates of the journeys concurred with the summer and late spring months, which potentially have the highest temperature values in Central Europe. These shipments originated from Hungary from different large automotive parts manufacturing plants to three different destinations: Uitenhage (Republic of South Africa), Changchun (China) and Aurangabad (India). Considering the location of Hungary and the location of these cities, all transits included several different modes of transportation (truck, rail and ship) and climate conditions. All the shipments used ISO containers in the forwarding of the automotive goods.

The measurement between Hungary and the Republic of South Africa was conducted between April 17, 2014 and July 7, 2014 for a total of 82 days. The unitized load first traveled from the manufacturing site to the storage facility near Miskolc, Hungary, and then to a central storage facility in Germany.

Table 1 Temperature and RH values of ISTA 3E (ISTA, 2017), ISO 2233 (ISO, 2000) and ASTM D4332 (ASTM, 2014)

Environment or Condition	Temperature [°C]	Relative Humidity [%]
Cryogenic (A) (ISO 2233, ASTM D4332)	-55 ± 3	-
Extreme Cold (ISTA 3E)	-29	-
B (ISO 2233, ASTM D4332)	-35 ± 3	-
Severe Cold (ISTA 3E), Frozen food storage (C) (ISO 2233, ASTM D4332)	-18 ± 2	-
Cold, Humid (ISTA 3E); Refrigerated storage (D) (ISO 2233, ASTM D4332)	+5 ± 2	85 ± 5
5, ISO 2233	+20 ± 2	65
Temperate high humidity (F) (ISO 2233, ASTM D4332)	+20 ± 2	90 ± 5
Controlled Conditions (ISTA 3E)	+23	50 ± 5 %
8, ISO 2233	+30 ± 2	85 ± 5
J (ISO 2233, ASTM D4332)	+30 ± 2	90
Hot, Humid (ISTA 3E)	+38	85 ± 5
Hot, Humid then Extreme Heat, Moderate (ISTA 3E)	+38 (72h), +60 (6h)	85 ± 5 % (72h), 30 ± 5 % (6h)
K (ISO 2233, ASTM D4332)	+40 ± 3	-
Tropical (L) (ISO 2233, ASTM D4332)	+40 ± 2	90 ± 5
Elevated Temperature (ISTA 3E)	+50	-
M (ISO 2233, ASTM D4332)	+55 ± 2	30
Extreme Heat (ISTA 3E)	+60	15 ± 5 %
Desert (ISO 2233, ASTM D4332)	+60 ± 2	15 ± 2

From here it again traveled by truck to the port in Bremerhaven (Germany). It then traveled by ship to a South African port, Port Elizabeth, with a stop in Algeciras (Spain). It was then unloaded from the ship and transported further inland by truck in South Africa to the final customer destination in Uitenhage (Republic of South Africa). On the ship, the container was loaded on the upper deck of the vessel.

The second measurement, between Hungary and India, was conducted between July 2, 2015 and September 8, 2015 for a total of 68 days. In this study the products first traveled by truck from the manufacturing site to Dunajská Streda (Slovakia), and then it traveled further by rail through Prague (Czech Republic) to a port in Hamburg (Germany). It then traveled by ship to Mumbai, Port Nhava Sheva (India) with stops in Tangire (Morocco), in Jeddah (Saudi Arabia) and in Jebel Ali (Dubai). The location of the container was on the second deck of the vessel. It was then unloaded from the ship and transported further inland by truck in India to the final customer destination in Aurangabad (India).

The third measurement, between Hungary and China, had a similar route to the previous journey. It was conducted between August 27, 2015 and October 19, 2015 for a total of 53 days. The shipping route was the same until Hamburg (Germany). It then traveled by ship to Tianjin Xingang (China) with a stop in Antwerp (Belgium). The container was loaded on the main deck of the freighter. It was then unloaded from the ship and transported further inland by truck in China to the final customer destination in Changchun (China).

The details of each route and specific locations where the load arrived by date are shown in Tables 2-4 and the routes are drawn in Fig. 1.

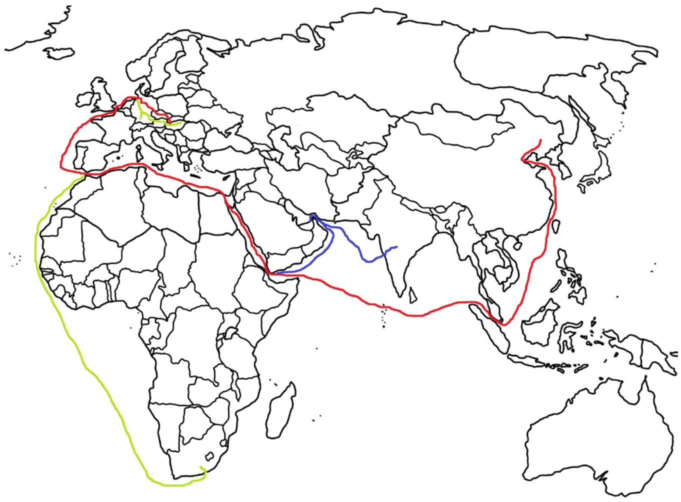

Fig. 1 Shipping routes of the transports measured

3.2 Instrumentation and set-up

A Lansmont (SAVER) TM 3X90 field data recorder (Lansmont Corporation Monterey, CA, USA) was used to record temperature and humidity.

On each route the recorder was mounted at the geometrical midpoint of the container on the floor. For all shipments an ISO 40' high cube container was used, as shown in Fig. 2. The settings of the recorder used in this study were the following:

- Interval between each reading:
  - HUN-ZAF: 10 min.
  - HUN –IND and HUN-CHN: 8 min.
- Temperature Measurement Range: -40° to 60°C
- RH Measurement Range: 5 % to 95 % RH.

Table 2 Details of the various stages of the HUN - ZAF shipment

Stage	Date	Transport Method	Location	Activity
EU Cont.	17 Apr – 18 Apr	-	Miskolc (HUN)	Indoor storage
	18 Apr	Truck	En route	Forwarding (9km)
	18 Apr – 25 Apr	-	Felsőzsolca (HUN)	Outdoor storage
	25 Apr	Truck	En route	Forwarding (1.053 km)
	25 Apr – 27 Apr	-	Bad Rodach (GER)	Outdoor storage
	27 Apr – 28 Apr	Truck	En route	Forwarding (305 km)
	28 Apr – 7 May	-	Reutlingen (GER)	Outdoor storage
	7 May	Truck	En route	Forwarding (727 km)
EU Port	8 May – 12 May	-	Bremerhaven (GER)	Outdoor storage
Maritime	12 May – 5 Jun	Vessel	En route	Forwarding (upper deck)
ZAF Port	6 Jun – 25 Jun	-	Port Elizabeth (ZAF)	Outdoor storage
Africa Cont.	25 Jun	Truck	En route	Forwarding
	26 Jun – 7 Jul	-	Uitenhage (ZAF)	Indoor storage

Table 3 Details of the various stages of the HUN- IND shipment

Stage	Date	Transport Method	Location	Activity
EU Cont.	2 Jul	-	Győr (HUN)	Indoor storage
	2 Jul	Truck	En route	Forwarding (40km)
	2 Jul – 4 Jul	-	Dunajska Streda (SVK)	Outdoor storage
	4 Jul – 5 Jul	Rail	En route	Forwarding (440 km)
	5 Jul – 6 Jul	-	Prague (CZE)	Outdoor storage
	6 Jul	Rail	En route	Forwarding (700 km)
EU Port	6 Jul – 9 Jul	-	Hamburg (GER)	Outdoor storage
Maritime	9 Jul – 12 Aug	Vessel	En route	Forwarding (1st deck)
India Port	12 Aug – 6 Sep	-	Mumbai (IND) Nhava Sheva	Outdoor storage
India Cont.	6 Sep	Truck	En route	Forwarding (50 km)
	6 Sep – 7 Sep	-	Shikrapur (IND)	Outdoor storage
	7 Sep – 8 Sep	Truck	En route	Forwarding (360 km)
	8 Sep	-	Aurangabad (IND)	Indoor storage

Table 4 Details of the various stages of the HUN- CHN shipment

Stage	Date	Transport Method	Location	Activity
EU Cont.	27 Aug	-	Gyor (HUN)	Indoor storage
	27 Aug	Truck	En route	Forwarding (40km)
	27 Aug – 29 Aug	-	Dunajska Streda (SVK)	Outdoor storage
	29 Aug	Rail	En route	Forwarding (282 km)
	29 Aug	-	Ceska Trebova (CZE)	Outdoor storage
	29 Aug – 30 Aug	Rail	En route	Forwarding (150 km)
	29 Aug – 30 Aug	-	Prague (CZE)	Outdoor storage
	30 Aug – 31 Aug	Rail	En route	Forwarding (700 km)
EU Port	31 Aug – 9 Sep	-	Hamburg (GER)	Outdoor storage
Maritime	9 Sep – 12 Oct	Vessel	En route	Forwarding (upper deck)
China Port	12 Oct – 18 Oct	-	Tianjin (CHN) Port Xingang	Outdoor storage
China Cont.	18 Oct	Truck	En route	Forwarding (924 km)
	18 Oct – 19 Oct	-	Changchun (CHN)	Indoor storage

3.3 Data Analysis

The measured temperature and RH values are shown as a function of time for all three shipments. The mean statistical values of the climate are described for each route, such as minimum, maximum and average temperature and RH. As previous studies gave limited knowledge about the European leg of the shipments, these stages in this study are analyzed in more detail than the other stages, especially for the daily temperature and RH shifts.

Fig. 2 Location of SAVER in the container

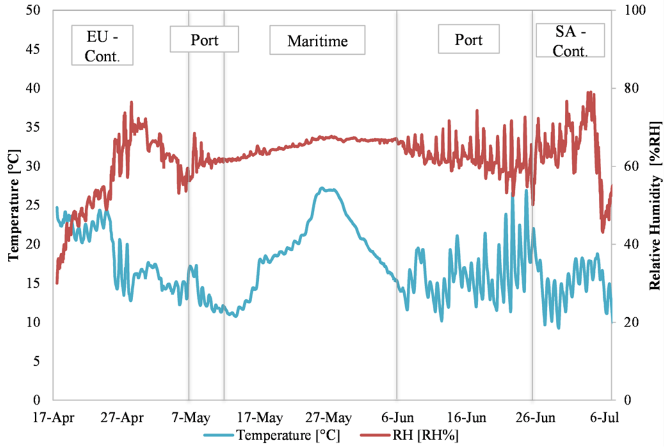

Fig. 3 Temperature and RH values from HUN to ZAF

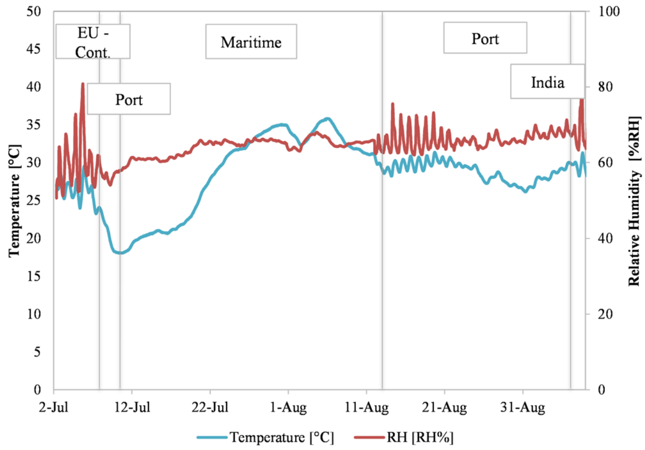

Fig. 4 Temperature and RH values from HUN to IND

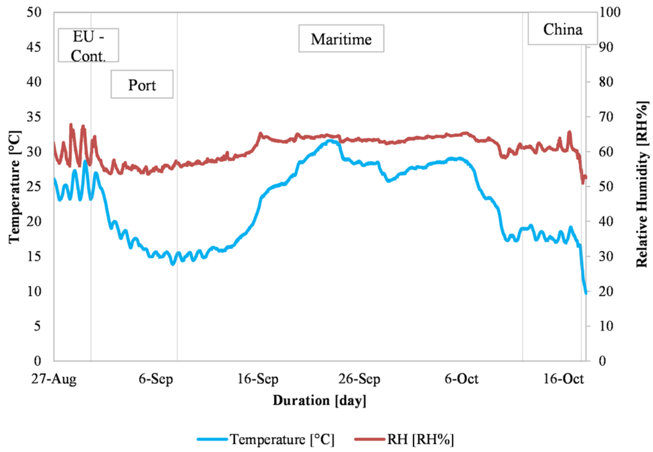

Fig. 5 Temperature and RH values from HUN to CHN

Minimum and maximum values are identified for all 24-hour periods continually for each shipment and the lowest and highest values were marked in the diagrams. The differences between the outside and internal (container) temperatures in the European ports were also compared. The proportion of the highest climate values, temperature and relative humidity distribution as a function of cumulative percentages [%] of the duration of total shipping is investigated. The measured temperature and RH values are rounded to the closest whole number. The Microsoft Excel "COUNTIF" function is applied to count the number of times a particular value appears in the list. These numbers are multiplied with a wake up interval time of the trigger and the proportion of each value can then be marked in diagrams.

4 Results and discussion

The first set of data discusses the recorded temperature and RH over the entire shipping route. Figs. 3-5 show the temperature and the relative humidity during the three shipments. Compared to Leinberger's paper these figures divide the shipments into 5 different stages because the storage times in the port were considerable. So, the first stage includes the time from filling the container until the container reached the port. The second stage is the period of storage in the European port. The third stage is the length in time of shipping at sea. The fourth stage is the periods of storage in the Asian or African port. The final stage consists of the inland transport to the respective customer's factory. Daily cycles of temperature and relative humidity were usually significant in the European Continent and in the ports. During maritime shipping these cycles were very minor and the changes were gradual.

Between Hungary and the Republic of South Africa the maximum and minimum temperatures were measured at 27.23 °C and 9.19 °C, with RH values varying between 29.98 % and 79.07 % RH. The shipment moved from Europe in the early summer season across the equator to South Africa in the winter season. The temperature changes were gradual with almost a linear temperature and constant level of relative humidity when the ship was near the equator. Table 5 contains the summary of temperature and RH values of all shipments.

Between Hungary and India the maximum and minimum temperatures were measured at 35.80 °C and 18.07 °C, with RH values varying between 50.50 % and 81.79 % RH. The highest

Table 5 Summary of temperature and RH results

	Temperature [°C]			Relative Humidity [%]		
	Min.	**Max.**	**Avg.**	**Min.**	**Max.**	**Avg.**
HUN - ZAF	9.19	27.23	17.5	29.98	79.07	62.2
HUN - IND	18.07	35.80	28.31	50.50	81.79	64.34
HUN - CHN	9.66	31.58	22.52	50.89	67.82	60.72

Table 6 Climate shifts in a maximum 24 h period in the EU continent

HUN - ZAF		HUN - IND		HUN - CHN	
Temperature shift [°C]	Relative Humidity shift [%]	Temperature shift [°C]	Relative Humidity shift [%]	Temperature shift [°C]	Relative Humidity shift [%]
8.8	19.31	5.56	28.61	5.72	12.02
in 23 h 50 min	in 13 h 50 min	in 11 h 48 min	in 13 h 44 min	in 11 h 12 min	in 2 h 56 min

daily climate cycles can be observed in the European continent and in the Indian port. The temperature and RH changes near the equator were similar to the Hungary – South Africa shipment, so there was a constant level of relative humidity (60-70 %) and almost a linear temperature increase.

Between Hungary and China the highest and lowest temperatures values were measured at 31.58°C and 9.66°C, with RH values varying between 67.82 % and 50.89 RH. As it can be seen, the RH did not reach 70 % due to the dry climate of the late summer months.

The second set of data analyzes the recorded temperature and RH in the first and second stages, which occurred in the EU continent. Figs. 6-8 show the recorded temperature and RH during the transport and storage stages in the EU continent for each shipment. The maximum temperature shifts in a maximum 24-hour period was also marked in each figure. These details were also summarized in Table 6. Figs. 6-8 also show the exact dates and times, so the exact locations are retrievable from Tables 2-4.

All routes had maximum climate shifts outside the EU continent except for the route with the destination of Aurangabad (India) and the HUN - CHN shipment (which had a difference in RH). The HUN - ZAF shipment had the maximum temperature change in Port Elizabeth (ZAF), 15.28 °C over 5 h 50 min.

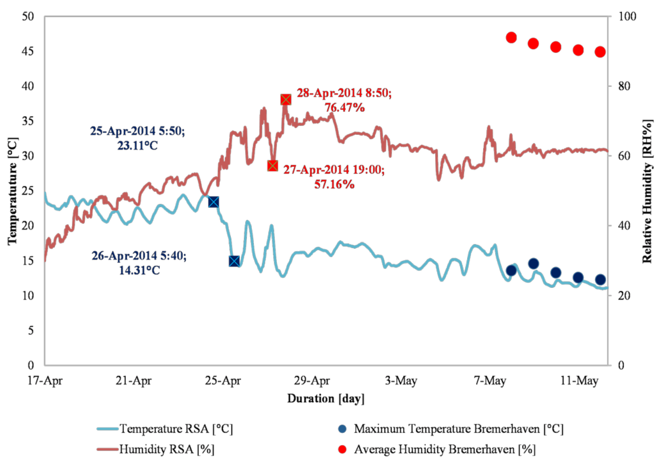

Fig. 6 Recorded values on the EU continent during shipping, HUN to ZAF

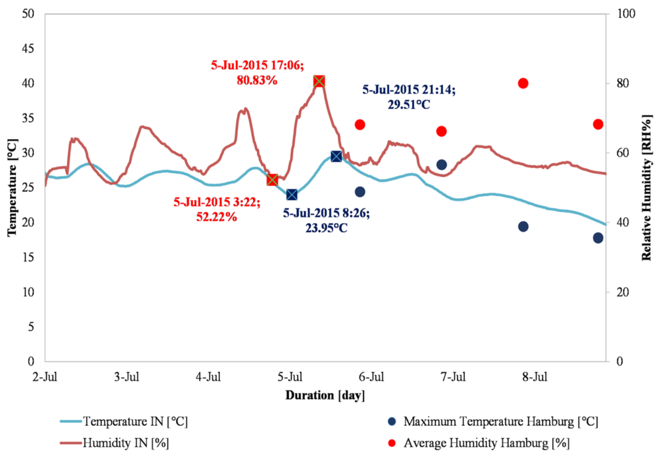

Fig. 7 Recorded values on the EU continent during shipping, HUN to IND

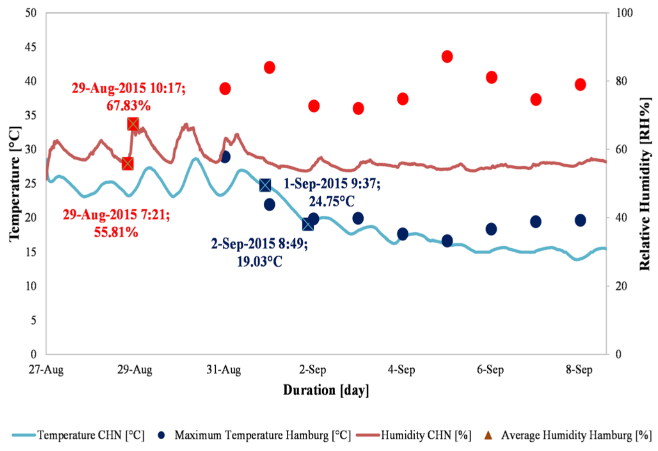

Fig. 8 Recorded values on the EU continent during shipping, HUN to CHN

The maximum RH difference was 29.91 % over a 24 h period during its storage in Uitenhage (ZAF). The HUN – CHN route had a temperature change of 7.28 °C over 20 h 32 min on the truck route in China.

Figs. 6-8 also contain the daily average temperatures and relative humidity of the ports. The results show that the real average RH values were always higher, than the internal values in the containers. The comparison of temperature values shows greater deviation, especially in Hamburg, with the shipment going to India. The difference could be highly influenced by the place of container, i.e., the side facing or side away from the sun or the real distance from the weather station. You can see below the GPS locations of these.

- Weather Station "Bremerhaven": Latitude: N 53.5331, Longitude: E 8.5758, Altitude: 6 m
- Bremerhaven Port: Latitude: N 53.5500, Longitude: E 8.5833°
- Weather Station "Hamburg-Neuwiedenthal": Latitude: N 53.4775, Longitude: E 9.8956, Altitude: 3 m
- Port of Hamburg: Latitude: N 53.50943, Longitude: E 9.96548.

The third set of data analyzes the temperature and relative humidity distribution as a function of cumulative percentages [%] of the duration of total shipping. Values are included for the different routes in Figs. 9-11. Some particulars from the graphs: 69 % of the total duration of shipping had a maximum temperature below 30 °C from Hungary to India. Also, the temperature was between 11 °C and 12 °C during 7 % of the total duration of shipping from Hungary to South Africa. The relative humidity was between 62 RH% and 63 RH% during 20 % of the total duration of shipping from Hungary to China.

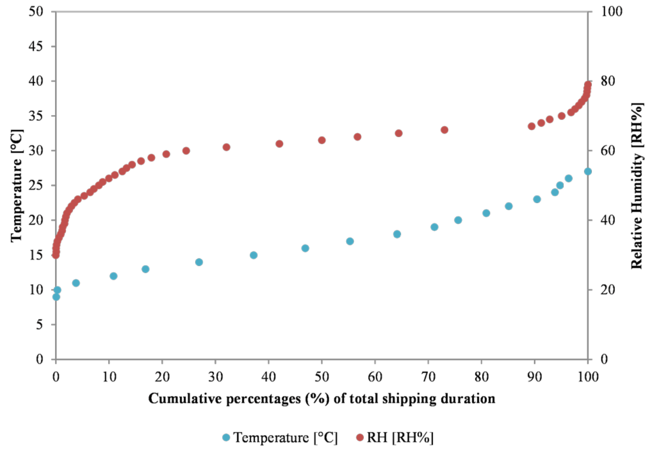

Fig. 9 The distributions of recorded temperature and relative humidity values from Hungary to the Republic of South Africa

The aim of this analysis is to quantify the exact total time until the products suffer due to the highest climatic stresses during their shipment. This data is very important in order to define the right climate profile for packaging testing, as transcontinental shipments usually take a minimum of 2 months but the condition time prescribed in packaging standards tests are usually only for 3 days (72 hours) (to minimize the cost and the time of the validation process). Table 7 contains the proportion of the highest temperature and RH range for each route. Some particulars from Table 7: the temperature was between 33 °C and 36 °C over a

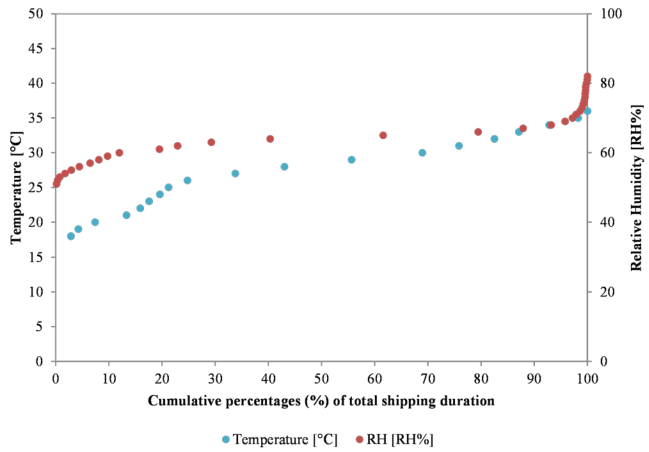

Fig. 10 The distributions of recorded temperature and relative humidity values from Hungary to India

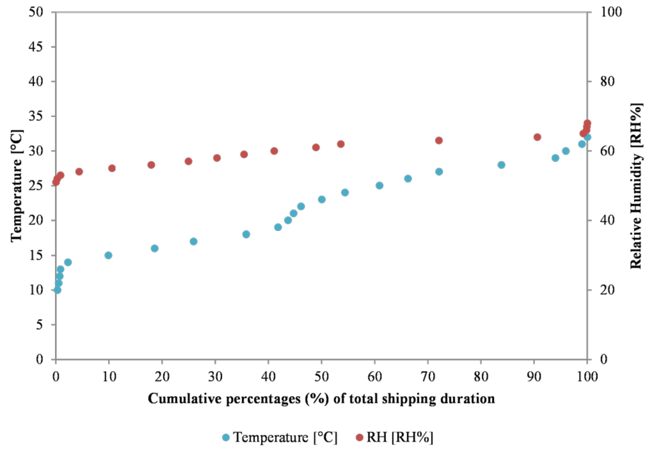

Fig. 11 The distributions of recorded temperature and relative humidity values from Hungary to China

Table 7 Proportion of the highest climate values

	Duration of total shipping [days]	72 h / Duration of total shipping [%]	Temperature [°C]	RH [%]
HUN - ZAF	82	3.65	26-27	71-79
HUN - IND	68	4.41	33-36	69-82
HUN - CHN	53	5.66	29-32	64-68

period of 72 hours during the journey from Hungary to India. The RH was between 71 % and 79 % over a period of 72 hours during the journey from Hungary to South Africa.

Figs. 12-13 show the profiles of Table 1 with the purpose of comparing the minimum and maximum temperature and relative humidity values of field-measured data.

Based on Table 7 the following climate profiles can be chosen using the analyzed shipping routes:

- HUN - ZAF: +30 ± 2 °C and 85 ± 5 %
- HUN - IND: +40 ± 2°C and 90 ± 5 %
- HUN - CHN: +30 ± 2 °C and 85 ± 5 %.

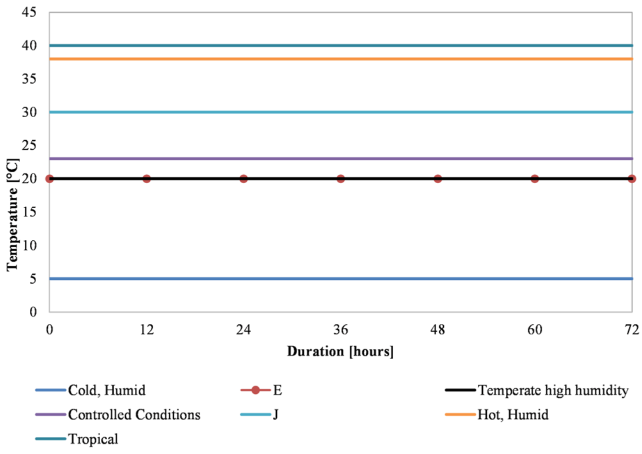

Fig. 12 Standard temperature profiles

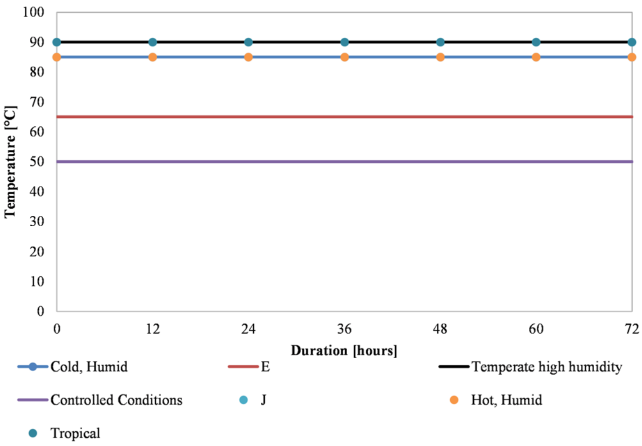

Fig. 13 Standard temperature profiles

4.1 Limitations of study

It has to be recognized by the readers of this paper that some circumstances of field measurements can significantly influence the results, such as the location of the recorder inside the container and/or the location of the container on the deck of the vessel and/or the changing of seasons in a given climate zone.

So for example the container on the top or side rows can be exposed to direct sunlight causing it to be warmer inside, while on the lower decks a relatively constant temperature and relative humidity can be recorded. On the other hand, when the temperature is higher in the upper area of the container the RH is higher in the lower region.

Due the above-mentioned points the recommended test schedules are not representative of the conditions when the container is located in the lowest or topmost rows of a vessel, or where the packaged product is in the upper area inside the container.

5 Conclusion

Three different shipping routes were observed to collect data on temperature, relative humidity and transit times of transcontinental shipments, which all originated from Central Europe. The results give a better understanding of climate details of transcontinental shipments from this region. Based on the results of this study the following conclusions can be drawn:

1. As previous studies stated the levels of fluctuations of temperature and RH are at acceptable levels during the maritime stages and the great daily fluctuations can be observed during the land transport and/or storage stages.
2. 50 % of the maximum temperature and RH shifts occurred on the EU continent and the daily fluctuations of climate conditions, despite the pretty short transport period, are significant.
3. The defined duration of (pre)conditioning testing time is only a few percent of the real duration of the total shipping routes, so the highest temperature and RH values have to be chosen from climate profiles. This paper proved that the top temperature and RH ranges occur mostly during the defined duration of conditioning testing time.

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