

EcoProduction.

Environmental Issues in Logistics and Manufacturing

Pawel Zajac

Evaluation Method of Energy Consumption in Logistic Warehouse Systems

EcoProduction

Environmental Issues in Logistics and Manufacturing

Series editor

Paulina Golinska, Poznan, Poland

About the Series

The EcoProduction Series is a forum for presenting emerging environmental issues in Logistics and Manufacturing. Its main objective is a multidisciplinary approach to link the scientific activities in various manufacturing and logistics fields with the sustainability research. It encompasses topical monographs and selected conference proceedings, authored or edited by leading experts as well as by promising young scientists. The Series aims to provide the impulse for new ideas by reporting on the state-of-the-art and motivating for the future development of sustainable manufacturing systems, environmentally conscious operations management and reverse or closed loop logistics.

It aims to bring together academic, industry and government personnel from various countries to present and discuss the challenges for implementation of sustainable policy in the field of production and logistics.

More information about this series at <http://www.springer.com/series/10152>

Pawel Zajac

Evaluation Method of Energy Consumption in Logistic Warehouse Systems

 Springer

Pawel Zajac
Faculty of Mechanical Engineering
Wrocław University of Technology
Wrocław
Poland

ISSN 2193-4614

EcoProduction

ISBN 978-3-319-22043-7

DOI 10.1007/978-3-319-22044-4

ISSN 2193-4622 (electronic)

ISBN 978-3-319-22044-4 (eBook)

Library of Congress Control Number: 2015948152

Springer Cham Heidelberg New York Dordrecht London

© Springer International Publishing Switzerland 2015

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made.

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media
(www.springer.com)

*This book is dedicated to my beloved wife,
Agnes, children Elizabeth and Charles,
who have always supported me
and were forgiving*

Acknowledgments

The book “Evaluation Method of Energy Consumption in Logistics Warehouse Systems” was reviewed independently by two investigators Professors: Professor Kazimierz Wojs Phd., D.Sc., Wroclaw University of Technology, Wroclaw, Poland and Professor Jerzy Kwasnikowski Phd., D.Sc., Poznan University of Technology, Poznan, Poland. In this place I would like to thank both for the positive reviews. Professors have wrote, among other things, that topic which is taken into consideration by the author is important and topical. The presented results of the work and the methods used in the book are new and interesting, so that might interest a wide circle of specialists.

Wroclaw, 2015

Contents

1	Introduction	1
1.1	Introduction	1
2	Thesis	7
3	Literature Overview	9
3.1	Achievements in the Assessment of Logistics Warehouse and Transport Systems	11
3.1.1	Overall LSM Structure	12
3.1.2	Capacity and Dimensions of Storage	13
3.1.3	Storage Capacity in LSM	13
3.1.4	Storage Dimensions	14
3.1.5	Layout of the Area/Storage Areas	15
4	Methods to Assess the Energy Consumption of LSM	31
4.1	Description of Model Evaluation of Energy Consumption LSM	40
4.2	Unloading, Admitting Freight Unit to the Warehouse	54
4.3	Vertical Displacement Energy	58
4.4	Horizontal Displacement Energy	65
4.5	Energy Intensity of IT Subsystem	70
4.5.1	Automatic Identification	72
4.5.2	Electronic Document Interchange in LSM	72
4.6	Energy Consumption Assessment of LSM	73
5	Experimental Research Results	93
6	Verification of the Model Evaluation of LSM	95
6.1	Evaluation of Dynamic Energy Intensity LSM	95
6.2	Evaluation of Energy Consumption of the IT System	99

6.3	The Use of Model Evaluation of Energy Consumption in LSM Management	103
6.4	Method to Assess the Energy Consumption of LSM with the Use of RESOLVER	117
	Summary and Conclusions.	125
	Utilitarian Results	127
	Appendix 1: Database of the Expert System.	129
	Appendix 2: Forklift Results	135
	References.	145

Abbreviations and Markings

Q_d	Heat penetrating through walls, ceiling and floor of the cooling chamber
Q_w	Heat dissipated from the refrigerated goods
Q_L	Heat delivered by air, which was introduced into the chamber unintentionally
Q_V	Heat associated with the air cooler fan
Q_{ah}	Any heat while defrosting
Q_{Ma}	Heat generated by lighting, machinery and related equipment in the warehouse
Q_{Me}	Heat generated by people
Q_S	Backup heat due to unforeseen changes of the heat load in the storage
G_i	Load weight (N)
G_k	Weight of carriage and working equipment (N)
G_r	Weight of internal frame (N)
W_t	Work of friction during movement of carriage and mobile frame of the lifting mechanism (N)
l_r, l_k	Distance from the center of gravity from the load with carriage to its gripping and carriage with mobile frame, respectively (l_r , can be assumed equal to l_k)
b_r, b_k	Spacing between retaining rollers of the carriage and mobile frame
d and d_1	Hub diameters of counter-pressure rollers of carriage and frame
D and D_1	Diameters of counter-pressure rollers of carriage and frame
f	Coefficient of friction in hubs
μ	Coefficient of friction of rollers rolling along the tracks
k	Coefficient taking into account other additional resistances (type of wheels and bearings—assumed at 1.1÷1.3)
G_{rg}	Weight of the main frame, including the tilt cylinder

0.75 and 0.25	Coefficients characterizing the approximate position of the frames' center of gravity
H_{\max} .	Maximum carriage lift height
D_c	Cylinder diameter (cm)
d_t	Piston rod diameter (cm)
p	Pressure (N/cm^2)
I_m	Cylinder capacity (assumed at 0.95)
v_t	Speed of piston movement (cm/min/.)
η_c	Volumetric efficiency of the cylinder, (using rubber and leather seals, approximately equal to 1)
G_I	Cargo weight (N)
v	Carriage lifting speed (platform) (m/s)
η	Coefficient of performance of the device mechanisms
k	Coefficient taking into account the impact of counterweight, equal to 04–06, when none $k = 1$
ΣW	Driving resistance of stacker crane along the track (N), set as for the track cart
$m \cdot a$	Forces of inertia
$W_t = f_t \cdot Q$	Movement resistances
f_t	Rolling resistance coefficient
$F(V)$	Drive force
ξ	Rotating mass factor
L	Conveyor length 70
μ	Rolling friction coefficient
v	Speed of cargo movement
η	Transmission performance
l	Length of the transferred load unit
B_r	Shaft length (m)
$K = 1$ or $K = 2$	Factors according to type of rollers (normal, heavy)
W_{edi}	Global ratio characterizing the suitability of EDI in organization (J)
w_i	Weight assigned to the i-th partial indicator
W_j	Value of the i-th partial indicator of EDI suitability

List of Figures

Figure 1.1	Energy intensity of warehouse processes. Author's own work	3
Figure 1.2	Energy intensity of long-distance transport terminals. Author's own work	4
Figure 1.3	Energy intensity of facilities [258]	5
Figure 1.4	Energy intensity of enterprises. Author's own work	5
Figure 4.1	Steps involved in creating LSM. Author's own work	32
Figure 4.2	The basic division warehouses based on [139].	32
Figure 4.3	From a single unit to warehouse space—the principle of filling up LSM space	33
Figure 4.4	Storage technologies in LSM [135]. Author's own work	33
Figure 4.5	LSM draft, taking into account the system's characteristic features. Author's own work based on [135]	34
Figure 4.6	Logistics storage system—components [136].	35
Figure 4.7	Diversification of energy supplied to the LSM. Author's own work	36
Figure 4.8	Storage costs for warehouses: a simple, b automated, c balanced. Author's own work	37
Figure 4.9	Line diagram of a forklift truck for an Case terminal with a goods lock: 1—SKU retrieval and turn backwards; 2—transport to the trailer; 3—placing the SKU; 4—relapse; 5—the empty truck goes back to the point of handover	53
Figure 4.10	Algorithm for the evaluation of energy intensity. Author's own work	57
Figure 4.11	Energy balance in a sample store [277, 278]	57
Figure 4.12	Diagram of the forklift's lifting mechanism.	59

Figure 4.13	Diagram of the forklift's hydraulic system	60
Figure 4.14	Diagram for the calculation of forklift lifting work.	61
Figure 4.15	Breakdown between conveyors [135].	67
Figure 4.16	Roller conveyor. Author's own work	68
Figure 4.17	Summary of the methods of exchanging information with a forklift operator. Author's own work [314].	71
Figure 4.18	Map of energy intensity of moving a pallet through the warehouse (assumptions as in Fig. 4.9). a Diagram of movement; b energy consumed (below the axis of energy recovery). Author's own work	83
Figure 4.19	Traction characteristics of forklift EFG2-20.	83
Figure 4.20	Course of acceleration of EFG-220 forklift with load	84
Figure 4.21	Acceleration time for EFG-220 forklift.	84
Figure 4.22	Energy consumption on traction during acceleration of the EFG-220 forklift.	84
Figure 4.23	Characteristics of a forklift truck braking system EFG-220.	85
Figure 4.24	Course of braking speed for forklift EFG-220 with load	85
Figure 4.25	Breaking time for forklift EFG-220	85
Figure 4.26	Energy consumption purposes forklift traction when braking	86
Figure 4.27	The time points of the methods of energy intensity evaluation. Author's own work	87
Figure 4.28	The dependence of fuel consumption on speed for an exemplary forklift truck.	89
Figure 4.29	The relation of time and speed and carrying capacity and speed [315].	90
Figure 5.1	Summary of the energy intensity of individual components of an office computer	94
Figure 6.1	Diagram for a shelf rack with characteristic dimensions for: DIS-2, RadioSchuttle, drive-in. Author's own work	97
Figure 6.2	Construction sketch of a shelving slot. Author's own work	99
Figure 6.3	Layout of the warehouse with dimensions. Author's own work	100
Figure 6.4	Diagram of forklift's travel in warehouse 1 (routes 1-5)	101
Figure 6.5	A view of the forklift's travel in warehouse 2 for the first five courses.	105
Figure 6.6	Illustration of a forklift travel (for the first five orders) in Warehouse	105

Figure 6.7 Summary of data and figures relating to the warehouse and the spacing of shelves. Author’s own work 106

Figure 6.8 Schematic of a rack section. Author’s own work 110

Figure 6.9 Diagram of the decision-making process of the advisory system part 1 121

Figure 6.10 Diagram of the decision-making process of the advisory system part 2 122

Figure 6.11 **a** Home page of the advisory system in ReSolver and **b** Case of rules in the expert system. 122

Figure A.1 Layout of the forklift route for comparative studies 135

List of Tables

Table 3.1	A summary of literature on warehouse layout design.	16
Table 3.2	The results of tests with models of time handling a corridor.	23
Table 3.3	Summary of studies on case studies	27
Table 3.4	List of LSM parameters.	28
Table 4.1	The efficiency of some conversions [80]	36
Table 4.2	Significance of coefficients of the usefulness of electronic data interchange	74
Table 4.3	Data for calculation.	74
Table 4.4	Calculations of forklift acceleration	74
Table 4.5	Data for braking calculations	75
Table 4.6	Calculation results for braking	76
Table 4.7	Calculations for minimum-time travel (S1 = 10 m, S2 = 50 m, S3 = 8 m, S4 = 60 m)	77
Table 4.8	Results of using the evaluation model of energy consumption.	87
Table 6.1	List of parameters	98
Table 6.2	Warehouse design parameters.	100
Table 6.3	Comparative results.	102
Table 6.4	Summary of total energy calculations for individual warehouses	102
Table 6.5	List of indicators of significance of introducing the system of electronic documents interchange	102
Table 6.6	Summary of data and figures relating to the warehouse and the spacing of shelves	103
Table 6.7	Summary data relating to values associated with the forklift truck and the cargo	104
Table 6.8	Summary of speeds achieved by the forklift along different sections of the route	104
Table 6.9	The dependence of energy consumption on the speed and the routes travelled for a truck with load (V_{max})	106