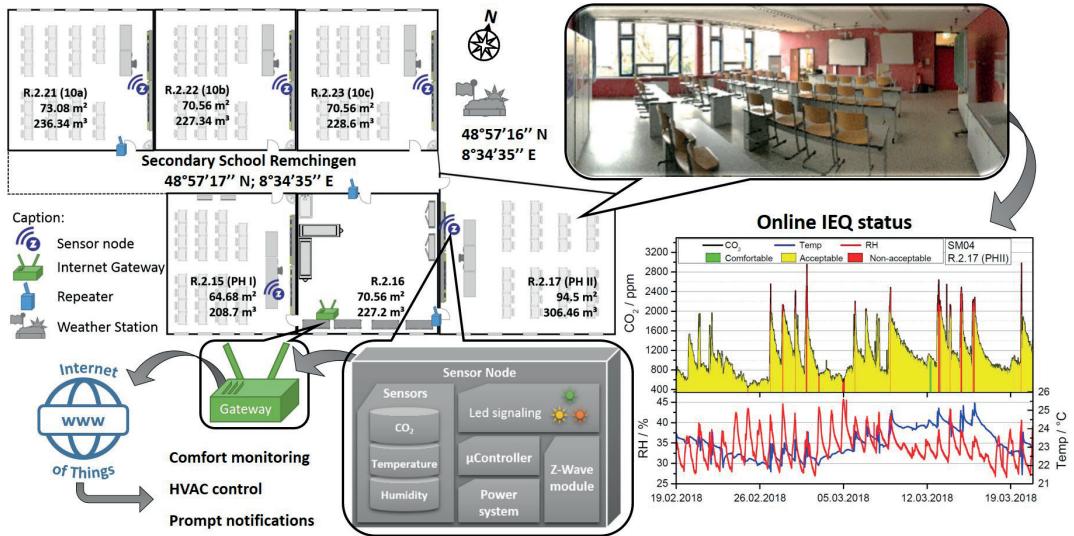


Smart Technologies for Indoor Environmental Quality Control



IMTEK, Universität Freiburg

**Dissertation zur Erlangung des Doktorgrades der
Technischen Fakultät der
Albert-Ludwigs-Universität Freiburg im Breisgau**

Smart Technologies for Indoor Environmental Quality Control

vorgelegt von

Álvaro Ortiz Pérez

Albert-Ludwigs-Universität Freiburg im Breisgau
Technische Fakultät
Institut für Mikrosystemtechnik
Professur für Gassensoren

Dekanin

Prof. Dr. Hannah Bast

Gutachter

Prof. Dr. Jürgen Wöllenstei

Prof. Dr. Leonhard Reindl

Betreuer

Prof. Dr. Stefan Palzer

Datum der Disputation

20.05.2019

Gas Sensors
herausgegeben von Prof. Dr. Jürgen Wöllenstein

Volume 9

Alvaro Ortiz Pérez

**Smart Technologies for Indoor
Environmental Quality Control**

Shaker Verlag
Düren 2019

Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at <http://dnb.d-nb.de>.

Zugl.: Freiburg, Univ., Diss., 2019

Copyright Shaker Verlag 2019

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the prior permission of the publishers.

Printed in Germany.

ISBN 978-3-8440-7093-4

ISSN 2566-8552

Shaker Verlag GmbH • Am Langen Graben 15a • 52353 Düren

Phone: 0049/2421/99011-0 • Telefax: 0049/2421/99011-9

Internet: www.shaker.de • e-mail: info@shaker.de

A los que siempre estuvieron y ya se fueron pero en el
corazón permanecieron.

To those who always were there and left but in the heart
remained.

Contents

Abstract	iii
Kurzfassung	v
1 Introduction	1
2 Indoor environmental quality	5
2.1 Thermal comfort	6
2.2 Acoustic and light levels	7
2.3 Indoor air quality	7
2.4 Improvement of indoor environmental quality and its implications	13
3 State of the Art	15
3.1 Non-dispersive absorption spectroscopy	18
3.2 Metal-oxide based gas sensing	26
4 System concept and design	33
4.1 System architecture & commercially available components	35
4.1.1 Main control unit	36
4.1.2 Power unit	37
4.1.3 Wireless transmission module	38
4.2 VOC sensing module	39
4.2.1 Temperature control unit	40

4.2.2	Sensing layer readout circuit	41
4.2.3	Metal oxide based virtual sensor array	42
4.3	Photoacoustic module for CO ₂	42
4.3.1	Photoacoustic detector	43
4.3.2	LED driver	47
4.3.3	Signal processing	47
4.4	System integration	50
5	Detection of volatile organic compounds and odor recognition	51
5.1	Functional materials and operational protocol	53
5.1.1	Sensing platform and materials	54
5.1.2	Measurement protocol and power consumption	58
5.2	System characterization and laboratory measurements	60
5.3	Exposure to stoma samples	67
5.4	Pattern recognition	69
5.5	Summary	72
6	CO₂ as indoor air quality indicator	75
6.1	CO ₂ sensor calibration	77
6.2	Ventilation and air exchange rates	81
6.3	Thermal comfort	83
6.4	Total IAQ rating	86
6.5	Analysis of CO ₂ background levels and ventilation rates	88
6.6	Summary	90
7	Conclusion	93
	Bibliography	97
	Publications	109
	Nomenclature	111
	Acknowledgments	115