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Experimental sorting of municipal-like waste in the hospital "Civico", Palermo (IT)

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Abstract: An experiment of source sorting - based management of Health Care Waste (HCW) was carried out in 2011 in 4 Departments of the Public Hospital "Civico" (Palermo, IT), where the basic mandatory separation between hazardous and non-hazardous waste was already going on since year 2000.The experiment consisted in weighing every day for 15 days 4 predefined fractions collected in the Infirmaries (namely paper, plastics, glass and unsorted fraction), and the bags with unsorted waste from the patient's stay room. Furthermore, in 1 of the 4 Departments also the boxes of Infectious Waste (IW) were weighed for a week.As a result a weighted average value of 0.56 kg of Municipal-like Waste (MLW) per bed and per day was obtained for the Infirmaries of the 4 Departments (1.89 kg for the whole Department). The potentially recoverable waste fractions of MLW were about 65.7 %, the balance being unsorted waste.The actual production of IW − monitored in just one of the Departments, OU 1− brought to a generation rate of 0.74 kg/bed-day with a range 0.50−1.00. This production represents the 54 % of total waste from that Infirmary but just 34 % of the overall waste stream from the Unit. This pilot experiment confirms the wide finding that IW are a minor part of the overall waste stream produced in a health care structure.

Keywords: Healthcare Waste, Infectious Waste, Municipal-Like Waste, Waste Management, Sorted Waste, Waste Collection

1. Introduction

According to the definition of the European List of Wastes − Chapter 18 − healthcare waste is "waste arising from any immediate healthcare activity". Principal sources include hospitals, veterinary surgeries, dental surgeries, General Practitioners' surgeries, blood transfusion centres, teaching and research establishments and public health laboratories. Incidentally, the term has replaced the former "clinical waste".

Examples of healthcare waste obviously include: infectious waste, laboratory culture, anatomical waste, used sharps, discarded medicines, laboratory chemicals and offensive waste from hospital wards or other healthcare environments. Healthcare wastes, however, may generally fall both in hazardous and non-hazardous categories.

Healthcare waste is not addressed by any special EU legislation [1]; nevertheless it is subject – among others – to the Waste Framework Directive [2] and to the classification of the European List of Wastes [3].

It is generally considered a serious issue due to Infectious Waste (IW), of which it is partially made up. Actually, several studies in the last years have demonstrated that IW are not the major fraction of total waste produced in a medical facility: about as much as it indeed can be considered a Municipal-like Waste (MLW).

As the disposal of IW is by far more expensive than of MLW and requires a high level of care, any source separation should be pursued [4, 5], and the relevant Act in force in Italy − *Decreto Presidente della Repubblica 254/03* – explicitly recommends it [6].

Still at the end of the Nineties the reported figures of waste production rates in medical facilities and institutions fell in a rather broad range (1 to 4 kg/bed-day and more),

although Country; size; and character of the Institution (principally, research hospital / health care only) had already been identified as the features affecting the production rate. Other important issues are: the definition of HCW or Medical Waste used by different Authors; the operational rules of the Hospitals, not always explained; and the way each survey was made. All this can affect markedly the value of generation rate, as has been stressed among others by Komilis and co-workers [7].

In the last ten years a wealth of data on waste production rates in Health Care Facilities have been gathered and compared; Table 1 shows a sample of them, with special attention to statistics from South−Eastern Mediterranean area.

Table 1. *Recent data on waste production rates in Health Care Facilities lying in Countries of Southern and Eastern Mediterranean area*

Healthcare Facilities		**Generation rate, kg/bed-day**		**City/Country**	**Authors**
Nature	**Size (bed nr.)**	**IW**	**MLW**		
State hospitals	11 222	---	---	Istanbul (Turkey)	Birpinar, 2009 [8]; *www.istac.com.tr [9]*
Private hospitals	7 902	---	---		
Social insurance institutions hospitals	6 763	---	---		
University hospitals	5 369	---	---		
Military hospitals	3 530	---	---		
Total	*34 786*	*~0.28*	*~0.40*	Istanbul (Turkey)	Birpinar, 2009 [8]; *www.istac.com.tr [9]*
University Hospitals	200−950	0.72	---	Greece	Komilis et al., 2012 [7]
Public and Private	27 005 (total)	0.13	1.04	Croatia	Marinkovic et al., 2008 [10]
Public (50%) and Private (50%) HCF	1315 (total)	0.62	1.49	Damanohour - El-Beheira Govt., Egypt	El-Salam, 2010 [11]

The outcomes of the most recent investigations concerning medical waste composition are depicted in Figures 1 and 2. Although their Authors [11, cit.; 12] had made weighing and analysis in the Wards distinct from the ones in general services and kitchens, the synthetic tables published actually focus on the physical composition of wastes, putting together the sources.

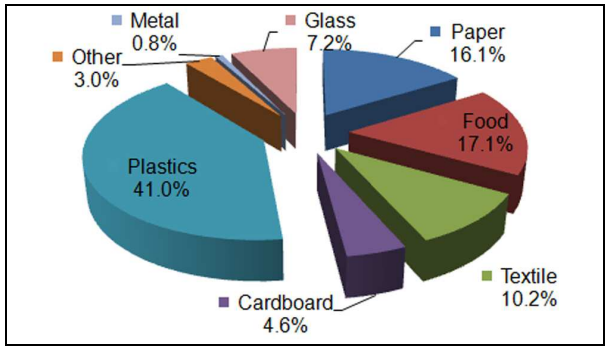


Figure 1. *Physical composition of HCW for Damanhour City, Egypt. Drawn on El-Salam's data [11, cit.].*

In Table 2 the figures published by El-Salam, 2010 [11, cit.] and by Altin, 2003 [12, cit.] are compared with those of this survey, anticipated here for reader's convenience. The main differences lie: a- in the high Plastics share in Turkish Hospitals (41 % of all waste), which "flattens" the other components; b- in the high Paper & Cardboard share issued from this survey, that was centered on Municipal-like Waste (MLW) (column 4).

Relatively few data have been published about MLW in hospitals, which in fact lend themselves to source-separated collection, followed by conventional disposal. The aims of this work were precisely, a- get first hand data on MLW production in a middle size hospital in Italy; b- verify the difficulties to face in switching to source separation; c- evaluate the environmental benefits, compared with the investment in materials and efforts.

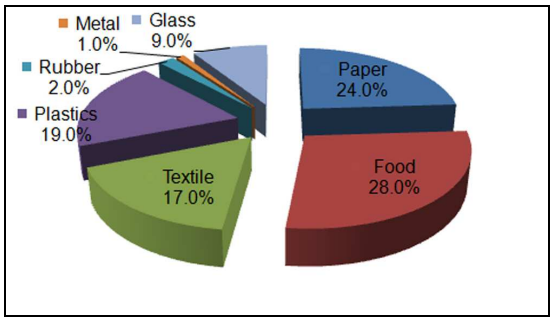


Figure 2. *Physical composition of HCW for Turkey. Drawn on Altin's data [12].*

Indeed, in a very recent and original paper, Soares et al. (2013) made the Life Cycle Inventory of disinfection of infectious waste [13]. This makes sense since for disinfection several possible processes exist, and each of them entails different amounts of equipment, reagents and energy.

For separate collection instead, the investments of any kind in bins and bags are almost negligible as well as the running costs for in-house handling. As environmental

benefits are nearly sure, LCI and LCA procedures lose some of their interest as a decision tool among alternative strategies.

Table 2. *Comparison among the results of three recent surveys on hospital waste. Figures in percentage.*

	Altin, 2003	El-Salam, 2010	This survey (municipal-like only)
Paper & Cardboard	20.7	24.0	33.16
Plastics	41.0	19.0	19.40
Glass (incl. Metals)	8.0	10.0	13.13
Textile	10.2	17.0	n.d.
Unsorted	20.1	28.0	34.30 (incl. Textile)

2. Methods

2.1. The Experiment: Departments and Operational Rules

The basic assumption of this experiment was that Infirmaries are the place where the MLW resulting from medical care can be effectively and skilfully kept separated from the others generated in the same activity (principally the Infectious), and also collected "sorted". Waste collected in bins kept in stay rooms was defined "unsorted".

Table 3. *Services provided by Health Care Facility "Civico", Palermo (IT), in the Year 2010*

Ordinary admission		
Nr. of cases	Days of stay	Beds in service
18 417	171 249	559
Day Hospital admission		
Nr. of cases	Nr. of medical visits made	Beds in service (for day care)
11 195	42 598	110

The "Ospedale Civico", Palermo, was taken as a suitable case study thanks to several favourable features. In the Year 2010 it gave to the public the services summarized in Table 3, which give a measure of its size and regional importance.

The current waste management rule in 2011 was (and still is) limited to separating and handling two main streams: hazardous / non-hazardous; further sorting only the hazardous ones according to their 3 risk profiles, that is: chemical / biological or infectious / radioactive.

To each type of hazardous waste the procedures prescribed by *Decreto 254/03* [6, cit.] are applied.

The Municipal-like Waste (MLW) generated in the Departments does not currently benefit of any special management, either internal (source separation) or external (sorted collection service by the Municipal Company). Before the experiment described in this paper was made, there were no data on MLW generation rates.

The experiment of source sorting was put in place in 4 Departments located in the same building. Before starting the experiment a special training of medical care staff on waste minimization was done.

Table 4. *Main relevant data for the 4 Departments with stay rooms involved in the experiment (Year 2010)*

	Ordinary admission (every day)				**Day Hospital admission** (250 days per year)			
Department	Nr. of cases	Days of stay accompl.	Beds in service	Average length of stay, d	Nr. of cases	Number of visits	Beds in service (for day cares)	Avg nr. visits / case
Thorax Surgery	450	3 262	8	7.2	157	326	2	2.1
Pneumology	480	6 188	16	13	203	920	2	4.5
Nephrology and Dialysis	520	4 472	12	8.6	357	2 501	5	7.0
Nephrology with kidney transplant	297	2 767	10	9.3	545	4 106	5	7.5

Figure 3. *Four types of containers left over from dressing or general care operations.*

The Departments participating were: Thorax Surgery; Pneumology; Nephrology and Dialysis; Nephrology with Kidney Transplant. The Bronchial Endoscopy Outpatients' Ward – connected to Pneumology – was also included, but Surgical Units themselves were excluded. Table 4 gathers the main relevant data for the Departments listed above.

Fig. 3 shows four types of containers discarded from dressing or general care operations and classified "non-hazardous, non-infectious"; either as such, or after being emptied and flushed. A lot of them are paper and cardboard packages; there is much plastic but little glass, all of it colourless.

Figure 4. *Plastic throwaway containers for thoracic cavity drainage.*

The transition from glass to plastics in medical devices has led to water and detergents saving and better hygiene, but has also dramatically increased the amount of throwaway items – often bulky – to dispose of. See Fig. 4 as an example.

In a typical Department, wastes are generated in all the 4 areas of which it is usually made up; Surgical Unit apart (where there is one). The status was described in Table 5 (following), specifying how the features ordinarily are at "Ospedale Civico", out the place and time of the experiment performed.

In Sicily there are no plants for RDF production through whatever process. As diapers and mattress-protecting stripes are made of LDPE + paper, today they are to be disposed of as "unsorted waste"; the same for non-woven white coats, non-contaminated latex gloves, etc.

Urine bags could in principle be emptied, flushed and handed over as plastics for recycle; in practice, though, since Materials Recovery Facilities use to reject them as objectionable, they are bound to be discarded with other unsorted waste also.

Table 5. *Ordinary features of waste management at "Ospedale Civico". Changes made for the experiment are stressed with bold characters*

Properties	Infirmary	Kitchenette + toilets	Offices	Patients' stay
Number of rooms	1	1 + 3	1 or more	2 or more
Types of waste generated in rooms	A- Municipal (such as paper, cardboard, plastics in form of packages, or other) B- Municipal – like (from medical care but non- or no longer contaminated) C- Generated by medical cares, and hazardous.	A- Municipal (such as packages made of paper, cardboard, plastics; remains of food; paper napkins; plastic cutlery; diapers …)	A- Municipal	A- Municipal (mainly paper and remains of food). Defined "infectious" in the Wards where airborne diseases are treated
Waste brought into the rooms	B; C	None	None	None
Staff	Constantly present	Frequently	Office hours	Regularly
Patients	For medical care	No	No	Constantly
Visitors	No	No	No	In the hours allowed
Waste containers (ordinarily)	• 1 for infectious • 1 for sharps • 1 for municipal and municipal-like, unsorted	1	1	1
Waste containers (this experiment)	• 1 for infectious • 1 for sharps • 4 for municipal and municipal-like, sorted (*)	Same as above	Same as above	Same as above

(*) Only 3 (no glass found) in the Bronchial Endoscopy Outpatients' Ward.

Table 6. *Essentials on the 4 Departments with stay rooms participating in the experiment*

Department	Identifying symbol	Generation rate, whole Dpt (kg/bed-day)	(Waste gener. in the Infirmary / waste in the whole Ward) (%)
Thorax Surgery	OU 1	1.8 ± 40%	41
Pneumology	OU 2	1.9 ± 22%	24
Nephrology and Dialysis (*)	OU 3	2.1 ± 14%	26
Nephrology with kidney transplant	OU 4	1.7 ± 60%	33
Weighted average		*1.89*	*30*

(*) Dialysis room itself was not included in the experiment.

As the Infirmaries are the only rooms constantly manned with trained staff, the experiment was centred on them. It lasted 3 weeks – included 2 weekends – during which a core of (30 x 4 x 5) = 600 bags were labelled, placed, taken up, checked, replaced and weighed. These duties were fulfilled twice a day (only once on Sundays), namely around 10 a.m. and 5 p.m..

For practical purposes the four Departments are

identified as in Table 6, where some results of this work are also anticipated. The amounts from Infirmaries are the sum of the three MLW fractions sorted plus the unsorted.

2.2. Definitions for Data Correlating and Processing

The results of labelled bags weighing were elaborated with the intuitive formulae defined below. For any i-th fraction sorted in one Infirmary we define the relative amount or share:

$$f_{i(sorted,\mathrm{inf})} = \frac{m_{i(sorted,\mathrm{inf})}}{\sum_i m_{i(sorted,\mathrm{inf})}} \tag{1}$$

This ratio can be written 4 times, i.e. for the 4 fractions paper and cardboard; plastics; glass; and "other" waste discarded (unsorted); for each Department, and every day.

Since, apart those from Infirmaries, the amounts of waste from stay rooms (unsorted, as stated in Table 3) are the only significant ones in every Ward, definition (1) of the fraction's share when applied to the whole Department – stay rooms included − becomes:

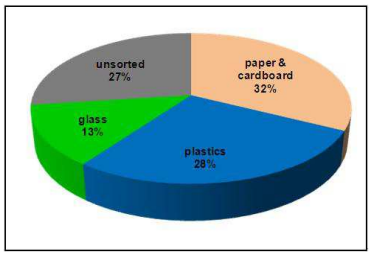
$$f'_{i(sorted,dpt)} = \frac{m_{i(sorted,\mathrm{inf})}}{\sum_i m_{i(sorted,\mathrm{inf})} + m_{(unsorted,dpt)}} \tag{2}$$

Also this ratio can be written 4 times; as the denominator is larger, it obviously gives smaller figures. The following ratio, instead, in a given Department and a given day has a unique value:

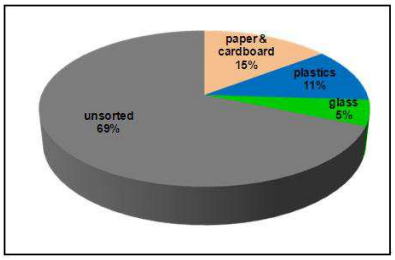
$$R = \frac{f'_i}{f_i} = \frac{\dfrac{m_i}{\sum_i m_i + m_u}}{\dfrac{m_i}{\sum_i m_i}} = \frac{\sum_i m_i}{\sum_i m_i + m_u} \tag{3}$$

3. Results and Discussion

3.1. Some Results in the Departments



(a)



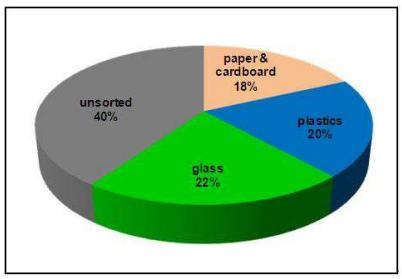
(b)

Figure 5. *OU 1 Thorax Surgery. (a) f for the Infirmary only; (b) f' for the whole Ward.*

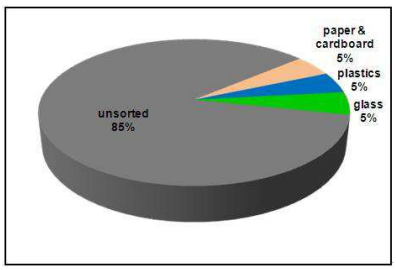
The following pie charts show the typical results in one Department (namely, OU 1 – Thorax Surgery). In Fig. 5 – (a) are the weighing outputs for the Infirmary only (fractions f, definition 1); (b) there are the same, recalculated as f' according to definition 2.

The heavy effect of unsorted waste from stay rooms is evident: recyclable waste in the Department drops from 73 to 31 %. Glass appears the minor part of sorted waste.

Department "OU 2" – Pneumology showed an even heavier effect of unsorted waste from stay rooms: comparing the two pie charts in Fig. 6, in fact, we see recyclable waste dropping from 60 to 15 %. Our explanation is that patients ailing with bronchitis, emphysema, pneumonia and like may need long stays (see Table 4, Column 5), with drip and aerosol cures, and perhaps oxygen, but less more; this results in larger amounts of waste produced in the rooms and smaller in the Infirmaries (Table 6, Column 4).



(a)



(a)

Figure 6. *OU 2 - Pneumology. (a) f for the Infirmary only; (b) f' for the whole Ward.*

3.2. An Outpatients' Ward: Bronchial Endoscopy of Pneumology

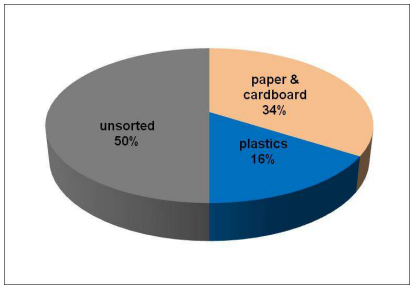


Figure 7. *Weighing outputs in Bronchial Endoscopy Outpatients' Ward of Pneumology OU.*

Inasmuch an Outpatients' Ward, here there are neither stay rooms nor kitchen. The waste generation rate must be calculated on the visits or care services given, without overnight stays. The result is 0.37 kg/service given. Practically no glass was discarded over the whole duration of the experiment.

The pie chart is a single one and is shown in Fig. 7.

The whole set of the results will be shown in the following section.

3.3 Generation Rate Indices Resulting

Tables 7 and 8 show the results of aggregating and indexing the results coming from sorting, collecting and weighing operations made in the 15 days.

Almost two−thirds of Municipal-like Waste collected in the Infirmaries, thus, are recyclable (row 5, column 6). Unsorted waste, if the remains of meals (prevailing) were collected apart from diapers, toilet paper etc., could actually make a good feedstuff for composting.

Table 7. *Breakdown of the sorted Municipal-like Waste collected in the 4 Infirmaries (composition %)*

	OU 1	OU 2	OU 3	OU 4	Overall (weighted)	Out of the recyclable matter only
Paper & Cardboard	32	18	32	37	33.16	44.7
Plastics	28	20	19	17	19.40	32.8
Glass (incl. Metals)	13	22	7	13	13.13 (*)	22.5
Total recyclable	***73***	***60***	***58***	***67***	***65.70***	***100.0***
Unsorted	27	40	42	33	34.30	---
TOTAL	*100*	*100*	*100*	*100*	*100.0*	---

(*) Included possible residues of liquids in bottles (0.25 e 0.5 dm^3) and phials

Table 8. *Aggregated and indexed amounts of waste resulting from the experiment*

Item	Index	OU 1	OU 2	OU 3	OU 4	Overall
A	Patients number (average)	10	16	13	10	49
B	Daily MLW generation in the whole Ward (kg/day)	17	31	27	16	91
C	Unit daily MLW generation rate, (B / A) (kg/bed-day)	1.8	1.9	2.1	1.7	1.89 (weighted)
D	Daily MLW generation in the Infirmary (kg/day)	7.4	7.2	7.2	5.6	27.4
E	Unit daily MLW generation in the Infirmary, (D / A) (kg/bed-day)	0.74	0.45	0.55	0.56	0.56
F	Unit daily generation of recyclables (kg/bed-day)	0.54	0.27	0.32	0.37	0.36 (weighted)
G	Ratio (E / C), arithmetic average	0.41	0.24	0.26	0.33	0.29
H	Ratio (E / C), weighted average	---	---	---	---	0.298

Table 9. *Environmental footprint of the materials collected as Municipal-like Waste (this 15 - days sorting experiment)*

	Overall % (weighted)	Abs. Amount (kg)	EE (MJ/kg)	EC ($kgCO_2$/kg)	MJ/ bed-day	$kgCO_2$/ bed-day
Paper & Cardboard	33.16	140.3	29.97	1.50	6.09	3.45
Plastics	19.40	82.7	80.50	2.53	9.65	3.43
Glass (neglecting metal traces)	13.13	51.2	15.00	0.85	1.11	0.71
Total recyclable	*65.70*	*274.2*	---	---	*16.85*	*7.59*

Fig. 8 shows the main values of Table 8 in a pictorial way.

For a further week, and in the Thorax Surgery Department only (OU 1), also IW were weighed while the daily number of patients was recorded. This part of the experiment yielded 12 more data. In this way it was possible to calculate the share of IW of the total amount of the Department waste.

As a rule, 2 boxes of IW are consigned daily, 60 dm^3 each; since their tare is 0.5 kg and a typical "filled up gross weight" is 5 kg, specific gravity of this kind of waste must be 75 kg/m^3, half of the value that the Authors themselves had found in earlier surveys [14, 15].

The measures and calculations made resulted in an average generation rate of 0.74 ± 30 % kg/bed-day. This makes up just 54 % of all waste (i.e. IW + MLW) generated in the Infirmary, and a 34 % of the whole Department.

When compared with the data arranged in Table 1, the result from this work appears very close to that from public hospitals in Greece (0.72) [7, cit.] and from a selected

number of Health-care facilities in Damanhour City, Egypt (0.66) [11,cit.].

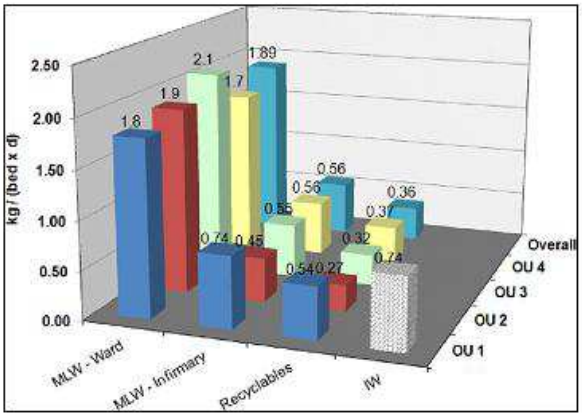


Figure 8. *Values of rows C, E and F of Table 8, plus IW unit generation rate in OU 1 only.*

3.4 Environmental Benefits of Source Sorting

The utility of implementing source – sorted collection systems for waste is unquestioned. The residual alternative stays simply in the "single–stream" collection (i.e., all dry waste commingled, but separated from wet) versus the various possible "multi-stream" ones.

In any given district, however, the choice about MLW source-sorting for a hospital Head Management is actually limited to few possibilities, because hospitals can't act disregarding their surrounding context. And environmental benefits are much like those of separated collection of domestic or municipal waste.

In Table 9 the indicators selected by Soares et al. [13, cit.] – namely, Embedded Energy and associated Carbon Dioxide − are arranged and applied to the recyclable materials weighed in the 4 Departments of "Ospedale Civico" during the 15 days of this survey. The source of EE and EC values is the University of Bath's database "Inventory of Carbon and Energy (ICE)" [16].

The results were indexed to the "bed in use" reference variable (columns 6 and 7). For a 1000 beds healthcare facility the total embodied energy of recyclable waste is therefore almost 17 000 MJ/day. Of course, actual recycle processes will originate waste, uses and emissions themselves; this lays out of the hospital's boundaries.

The enhanced operational safety, and the savings, gained thanks to separate waste collection, are the main benefits. Using the labelled bins in fact ought to be more attracting – even for hurried staff – than dropping small or big amounts of MLW into the IW boxes; an incorrect practice resulting in undue expenses and material resources losses.

4. Conclusions

The breakdown of the daily unit production rate of waste, calculated at the end of the experimental sorting in four Departments of Ospedale Civico, Palermo (Surgery Units not included), resulted in the following figures.

The overall generation of Municipal-like Waste (MLW) was 1.89 kg/bed-day; out of this, 0.56 kg (weighted average value) was obtained for the Infirmaries; the potentially recoverable fraction was about 65.7 %, the balance being unsorted waste. Unsorted waste for the four Departments was therefore 1.53 kg/bed-day.

Such amount is even larger than the customary daily unit production rate in towns. We are drawn to deduce that huge amounts of food, plus discarded books, newspapers, packaging trays, flowers etc. are dropped commingled in the bins kept in stay rooms.

Segregation at the source would be beneficial from every standpoint; composting of organic fraction remaining could be relatively easy. It should be kept in mind, though, that this does not hold for the Wards where airborne diseases are treated, as remains of meals here are suspected a priori.

The actual production of IW contemporarily monitored in one of the Departments brought to a generation rate of 0.74 kg/bed-day with a range 0.50−1.00. Evidently, this accounts just for a minor part of the overall waste stream produced in a health care structure.

It is hardly the case of stressing that a low specific apparent gravity, in the standard boxes with which IW are handed over to the external collection and hauling service, can give origin to unduly disposal costs for Hospitals.

This because IW disposal prices in principle are set proportional to the weight taken up; in many cases − however − the sealed boxes are simply counted at the gate, and weighed just occasionally as grab samples. So it may happen that a batch presumed for instance to weigh 150 kg/m^3 − if actually as low as 75 kg/m^3 − requires twice as much boxes and is paid twice the right to the Company.

Real involvement of health care staff confirmed itself as an invaluable contribution to strategies of waste reduction and of prevention of undue "over−classification". Infectious and unsorted waste can be effectively minimized with remarkable advantages in economy and in quality of life at the workplace.

No real drawback arouse in the Wards where the bins were put. There should not be any justifiable reason, then, for further delaying separate collection of MLW in Hospitals. Sometimes, however, it may be difficult to find room to place and give access to four distinct bins in old-dated buildings.

Acknowledgements

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Nomenclature

f ≡ share of any fraction on all sorted fraction

f' ≡ share of any fraction on total waste (sorted + unsorted)

References

[1] G. Wolff, "Health care waste management in the European Union," European Medical Waste Conference, Amsterdam (NL), 8 and 9 February 2011. http://www.emwc2011.org/

[2] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives. Official Journal of the European Communities, 22.11.2008.

[3] Commission Decision 2000/532/EC of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC on hazardous waste. Official Journal of the European Communities, 6.9.2000.

[4] A. Prüss, E. Giroult, P. Rushbrook, Safe management of waste from health-care activities, World Health Organization, Geneve (CH), 1999.

[5] E. Vecchi, M. Martignani, S. Ferretti, P. Marchegiano, S. Cencetti, "La Raccolta Differenziata: il caso del Policlinico di Modena," in RS Rifiuti Solidi, XXIII (5), CIPA Editore, Milano(IT), 2009, pp.327–339.

[6] Decreto Presidente della Repubblica 15 Luglio 2003, n. 254: Regolamento recante disciplina della gestione dei rifiuti sanitaria norma dell'articolo 24 della legge 31 luglio 2002, n. 179. G.U. Repubblica Italiana 11.9.2003, n. 211 (Italian legislation)

[7] D. Komilis, A. Fouki, D. Papadopoulos, "Hazardous medical waste generation rates of different categories of health-care facilities," Waste Management, vol. 32, pp.1434–1441, 2012.

[8] M. E. Birpinar, M. S. Bilgili, T. Erdoğan, "Medical waste management in Turkey: A case study of Istanbul," Waste Management, vol. 29, pp.445–448, 2009.

[9] ISTAÇ A. Ş. ©, Istanbul Environmental Management in Industry and Trade Inc., an affiliate of Istanbul Metropolitan Municipality, www.istac.com.tr

[10] N. Marinković, K. Vitale, N. J. Holcer, A. Džakula, T. Pavić , "Management of hazardous medical waste in Croatia," Waste Management, vol. 28, pp.1049–1056, 2008.

[11] M. M. A. El-Salam "Hospital waste management in El-Beheira Governorate, Egypt," Journal of Environmental Management, vol. 91, pp.618–629, 2010.

[12] S. Altin, A. Altin, B. Elevli, O. Cerit, "Determination of hospital waste composition and disposal methods: a case study," Polish Journal of Environmental Studies, 12, (2), pp.251–255, 2002.

[13] S. R. Soares, A. Rodrigues Finotti, V. P. da Silva, R. A. F. Alvarenga, "Application of life cycle assessment and cost analysis in health care waste management," Waste Management, vol. 33, pp.175–183, 2013.

[14] S. Nicosia, A. Lima, P. A. Lanza, G. Viviani "Physical features of health care waste," in ANDIS Toscana (ed.) Proceedings of the International Symposium of Sanitary and Environmental Engineering "SIDISA'08" ANDIS / ABES / AIDIS. Firenze (IT), 24 – 27 June 2008

[15] S. Nicosia, P. A. Lanza, M. Mosca, A. Lima, "Health care waste production: measures and estimates in "V. Cervello" hospital, Palermo, Italy," in Guzović Z., Duić N., Ban M. (eds.) Proceedings of the 5th Dubrovnik Conference on Sustainable Development of Energy, Water and Environmental Systems (SDEWES09), Dubrovnik (HR), 29 Sept. – 3 Oct. 2009

[16] G. Hammond, C. Jones, Inventory of Carbon & Energy (ICE) Version 2.0, University of Bath, UK, 2011. http://www.bath.ac.uk/mech-eng/sert/embodied/